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RESEARCH
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Operational-Requirements - Cost-Effectiveness Study of QMR for a New ¼-ton Truck

RAC

SYSTEMS ENGINEERING
MOBILITY TECHNOLOGY DIVISION
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Operational-Requirements - Cost-Effectiveness Study of QMR for a New 1/4-ton Truck

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FOREWORD

Research Analysis Corporation Project RP-127 was initiated 10 January 1964 to conduct an operational requirements/cost-effectiveness study for an austere, low-cost personnel and weapons carrier with a rated payload of $^{1}/_{4}$ ton intended to replace the present Truck, Utility, $^{1}/_{4}$-ton, 4 x 4, M151. This study includes data that could be used in determining the feasibility of developing a vehicle capable of being self propelled over inland waterways at speeds of up to 4 mph without special preparations.

Statistical data were compiled with the assistance of Lt Col Glen W. Smith, Military Advisor, and technical personnel of the truck and automotive industry. These data were analized for making a technical evaluation of the proposed vehicle and formulating the specifications for vehicle performance with their related costs. The object of this study is to provide sufficient information for a basis on which to make judgments in design tradeoffs from which vehicle specifications could be established in order to have the most effective vehicle for its cost.

Samuel A. LaMar
Chief, Mobility Technology Division

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Problem

(a) To evaluate the effect of the essential and desirable performances and physical characteristics proposed in the Army's qualitative materiel requirements (QMR) for the $\frac{1}{4}$-ton truck on its operational capability, reliability, maintainability, and cost and (b) to recommend to the Office of the Chief of Research and Development (OCRD) whether to continue procurement of the present M151 vehicles, procure commercially available vehicles, or design and develop a new vehicle concept.

Facts

In October 1960, US Continental Army Command (USCONARC) submitted the result of a study to CRD recommending replacement of the current standard M151 truck by a new $\frac{1}{4}$-ton 4×4 utility truck. In August 1963 the Department of the Army directed that a new QMR for a $\frac{1}{4}$-ton truck be developed stressing simplicity, durability, ease of maintenance, and lower cost than that of the M151 $\frac{1}{4}$-ton truck. When the QMR was completed, RAC was asked by the Army to undertake a study of the problem.

Discussion

In order to accomplish the intended objective, an approach was formulated that divides the effort into a number of phases:

(a) Review the QMR (reproduced in App A)
(b) Collect and compile data
(c) Evaluate and analyze data
(d) Perform computations and interpret data, considering trade-off factors
(e) Formulate conclusions and recommendations

The initial phase concerned itself primarily with understanding the specified requirements and the military characteristics contained within the QMR. The collection of data involved the acquisition of engineering design drawings, specifications, and cost data from various truck and component manufacturers. This was accomplished by letters of inquiry, telephone calls, and personal contact with engineering management personnel in industry. This study evaluated four separate concepts:

(a) Modifying the present M151 for the purpose of reducing cost by incorporating high-production commercial components, eliminating items or components where possible, and improving reliability of the vehicle by modifying components where statistical data indicate this to be desirable.

(b) Modifying the present commercially available vehicles such as the jeep and the Scout to meet military requirements.

(c) Designing a new vehicle concept incorporating the best features of the present $\frac{1}{4}$-ton utility truck and the commercially available vehicles.

(d) Designing a vehicle concept having amphibious capabilities without compromising on land mobility and without substantially increasing vehicle cost.

Various truck manufacturers were contacted to determine what their objections were in reference to the proprietary rights clause and what effect if any this clause may have on vehicle design. In addition an effort was made to determine the effect of providing commercial spare parts in the present military system compared with the limiting of advances in the state of the art in order to continue use of Ordnance-approved components. Manufacturers were encouraged to express their opinions as to the use of rigid specifications and related costs on items such as radio suppression on the electrical system, waterproofing and fungusproofing electrical components, painting of vehicles and many of the components, and close tolerances specified on drawings. This study also considered the various kits that could be adapted to the basic vehicle, cost effect of increasing procurement quantities, and the importance of maintaining continuity of a program.

All applicable data were evaluated for trade-off considerations in regard to utility, mobility, reliability, compatibility, maintainability, productibility, transportability, and initial and overall costs. The result of these studies and considerations are summarized and presented in Table 1.

Conclusions

1. This study has revealed that a vehicle can be produced to meet all essential requirements specified in the QMR for a new $\frac{1}{4}$-ton truck, with the exception of reliability.

Reliability as stated in the QMR is unrealistically high and beyond the present state of the art. There will be some reduction of land mobility due to the floating capability requirements. The cost of the floatable vehicle would be higher than the desired target cost by 46 percent.

2. An austere vehicle can be produced for the desired target cost of $1900, but this vehicle would not be the most effective vehicle for its initial and operational cost.

3. The vehicle determined to be most suitable by this study does not differ greatly from the present M151.

TABLE 1

Summary of Vehicle Performance

Requirement	In QMR	Meets requirements		Added requirement cost or saving[a]			Remarks
		Austere vehicle	Recommended vehicle	QMR vehicle	Austere vehicle	Recommended vehicle	
Floatability	Yes	No	No	$ 260.00	—	—	Cost based on modifying M151; for QMR and recommended vehicle replace M151 25-amp dc generator and regulator with 60-amp alternator; for austere vehicle replace 25-amp dc generator and regulator with 35-amp commercial alternator
Radio suppression	Yes	No	Yes	70.90	($54.00)	$ 70.90	
Air droppable	Yes	Yes	Yes	Basic design requirement			
60 percent longitudinal slope							
40 percent lateral slope							
Brake stopping power							
300-mile cruising range							
Cross country							
Maximum speed 50 mph							
Minimum speed 2½ mph							
30 mph up 6 percent grade							
18-ft turning radius							
60 deg angle of approach							
45 deg angle of departure							
4-wheel drive							
4 man-hours organizational repair time							
12 man-hours field repair time							
500 lb payload + two men		Yes					
4 personnel + equipment		No		—	(22.60)	—	Austere vehicle requires rear-seat kit to fulfill requirement

TABLE 1 (continued)

Requirement	In QMR	Meets requirements		Added requirement cost or saving[a]			Remarks
		Austere vehicle	Recommended vehicle	QMR vehicle	Austere vehicle	Recommended vehicle	
Spare tire		Yes			Basic design requirement		
Glove compartment		Yes			Basic design requirement		
Lifting and tie-down eyes		No		—	(6.74)	—	Eliminated on austere vehicles
Turn signals		Yes			Basic design requirement		
Tire-chain c!-arance		Yes			Basic design requirement		
Maximum curb weight 2700 lb		Yes			Requirement easily met		
Swimming (4 mph)	Yes	None		—	—	—	Swimming requirement can be met by each configuration, at a cost of $3200 based on the recommended vehicle
Wide range of liquid fuels		None					Requirement deleted by other engine considerations
95 percent mission reliability	Requirement cannot be met						
90 percent probability of:							
15,000 miles without minor overhaul	Requirement cannot be met						
25,000 miles without major overhaul	Requirement cannot be met						
Storage degradation:							
3 percent/yr in depot	Yes	Yes					
6 percent/6 months in field							
Maintenance intervals:							
6 mo organizational							
1 yr field		Yes					
Time allowed for failure diagnosing, min							
Organizational 20–30		Indeterminate					Requirements are a function of skill level and test equipment
Field 90–120		Indeterminate					
Tow ¼-ton trailer		Yes					
Transportability		Yes					
Cross country							
Fuel economy							
On-vehicle materials							
Inclement-weather kits							

Windshield-design	↓	↓	↓			
Human-engineering						
Maintainability	Yes		Yes			
$1900 target cost	No	Yes	No		See below	
Vehicle systems:						
Cooling	M151 with commercial hose clamps and cap	M151 with commercial hose clamps and cap	M151 with commercial hose clamps and cap	(2.04)	(2.04)	(2.04)
Fuel				—	(30.27)	(20.60)
Carburetor		Commercial	Modified M151[b]			
Fuel pump		Diaphragm	Diaphragm			
Exhaust				—	(1.00)	—
Muffler	Military specification	Commercial	Stainless steel			
Electrical	24-volt system	12-volt system	24-volt system	—	(53.76)	—
Alternator	60-amp, military specification	35-amp, commercial	60-amp, military specification			
Batteries	Two, military specification	One, military specification	Two, military specification			
Starter	Military specification	Commercial	Military specification less waterproof requirements			
Power train				—	(204.00)	(185.00)
Engine	M151	Modified M151	Modified M151			
Transmission	Military specification 4-speed	Commercial 4-speed	Commercial (modified) 4-speed			
Transfer	Military specification Single range	Commercial Single range	Commercial (modified) Single range			
Differential	Military specification (without power lock)	Commercial (without power lock)	Commercial (with power lock)			
Suspension springs	Split axle Coil	Through axle Leaf	Through axle Leaf	—	—	—
Brake	—	Commercial plating	Commercial plating	—	(3.20)	(3.20)
Wheels and	Military specification 7/16 × 20 studs and nuts	Commercial ½ × 20 studs and nuts	Commercial ½ × 20 studs and nuts	—	(41.00)	(3.00)
tires	Military specification	6.70 × 15 2-ply rayon Commercial	Military specification			
Body	Hull for floatability	Modified M151 (rear seat and door-curtain kits)	Modified M151	—	(112.13)	(35.00)
Miscellaneous				—	—	(50.00)
Total estimated added cost or saving				330.00	(566.74)	(200.00)
Cost of M151				2440.00	2440.00	2440.00
Total estimated cost				$2770.00	$1900.00	$2250.00

[a]Amounts in parentheses are savings.

[b]Eliminate deep fording kit modifications.

This vehicle would meet all the requirements stated in the QMR with the exception of the degree of reliability required and the floating capability. The cost of this vehicle is estimated to be $2250. This is less than the cost of the M151, which is $2442. This reduction can be accomplished through use of existing commercial components having equal or greater reliability than those now used on the M151, such as the transmission, differentials, and suspension system. In addition, cost saving can be made by deleting the waterproofing requirements in the electrical system and eliminating the adapters for the deep fording kit. The cost of the necessary engineering and tooling to accomplish these changes would be relatively small compared to that of a completely new vehicle development program. The reliability of the M151 has been determined and found to be good. The reliability of a completely new vehicle would in all probability be quite poor until numerous and costly modifications have been made to correct deficiencies found as a result of tests and reports by the user.

4. Although data are lacking for a definitive comparison, the use of a commercial vehicle under field conditions would result in a higher operational cost than that of a military vehicle. In addition a larger number of spare parts would be required, and cost due to downtime would be higher.

Unlike military vehicles, commercial-type vehicles are designed to meet limited specific terrain and environment. They are produced with the knowledge that their reliability is limited to a specific mission, and a degree of dependability can be sacrificed for the low initial cost. Without additional and comprehensive study the effect on total investment and operational cost that could be increased by a decision to develop an austere vehicle cannot be assessed at this time.

5. If a swimming or floating capability is required, the vehicle should be amphibious, having a minimum water speed of 4 mph.

It is estimated that an amphibious vehicle could be designed and produced for $3200 in quantities of 10,000 units per year for a period of 3 years. This program, however, would require considerably more lead time than the recommended vehicle program.

6. Vital failure information is not available to the designer.

Recommendations

1. A vehicle not greatly different from the present M151 is recommended.
2. The proposed military requirement for the $\frac{1}{4}$-ton utility truck should be restated, deleting floating or swimming capabilities.
3. A low-level effort should be made to exploit the amphibious vehicle by initiating a design and development program that would include model water testing, vehicle prototypes, and engineering and user tests.

On completion of this amphibious vehicle program a limited number of these vehicles could be produced to supplement the $\frac{1}{4}$-ton trucks in the field. As the amphibious vehicles become more reliable and their utility value for the cost becomes more acceptable, these vehicles could eventually be produced in quantities to replace the present $\frac{1}{4}$-ton utility trucks.

4. It is recommended that reliable high-production commercial components be substituted for some of the major and minor components of the present $^1/_4$-ton truck.

There are two approaches to this final design, either of which will result in the best vehicle for its cost: (a) modify the present M151 to incorporate the recommended commercial components, (b) prepare a new design incorporating as many of the present M151 components as possible. The choice between the two methods should be made by the successful contractor after completion of the general arrangement drawings with the approval of the cognizant government agency.

5. In order to benefit from experience and discoveries that accompany a hardware development program, the QMR or REPD should implement a method of trade-off considerations for cost effectiveness.

The engineering and service test criteria are the basis for design acceptance and subsequent type classification. The Test and Evaluation Command, with the help of various test boards, formulates a testing plan to which test rigs or prototype models are subjected. These tests are performed to determine whether the design meets the requirements specified in the QMR. There is very little flexibility in the test and evaluation program, since its mission is fixed by the QMR. This rigidity can and probably does force the contractor to design the vehicle to meet the requirements and pass the plan of test without the advantage of implementing trade-off considerations. An authorized person or committee should be in a position to permit rapid acceptance or incorporation of sound recommendations and suggestions made by the contractor, which would result in vehicle or component design based on the best compromise between cost and effectiveness.

6. A new or improved definition of reliability and maintainability should be specified so that these parameters will have a common meaning to personnel concerned.

Reliability should be indicated in the form of total number of hours or miles of operation before major overhaul or replacements are required. In addition, scheduled or unscheduled maintenance of major components should be specified by definite time limits. This would provide an acceptable, practical, quantitative measure of reliability and maintainability and would result in the desired level of reliability and maintainability.

7. Failure reports now available are useful to supply and maintenance planners but have limited meaning to the designer. These failure reports do not state why or how a part failed. This information is vital to the designer.

Much statistical data have been compiled and made available on component failures reported by users in the field. These statistical data are used in determining the spare-parts requirements to support the vehicles in the field, but a component such as a clutch or an inadequately designed spring, which could easily have been corrected for future production, is not documented in the failure report. If these data were available, reliable components could be produced, which would have an overall beneficial effect on the vehicle's reliability and cost.

Operational-Requirements - Cost-Effectiveness Study of QMR for a New ¼-ton Truck

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INTRODUCTION

RAC received a contract from OCRD to evaluate the effect of the proposed essential and desirable performances and physical characteristics on operational capability, reliability, maintainability, and cost of the proposed ¼-ton utility truck. On 10 January 1964 a study RP-127 was established. The purpose of this study was to evaluate the Army's QMR (reproduced in full in App A) and to make recommendations to OCRD whether to continue procurement of the present M151 vehicles, procure commercially available vehicles, or design and develop a new vehicle concept. At the same time ATAC solicited proposals from industry for the production of a vehicle that would meet the specifications based on the QMR.

The study was approached by reviewing the requirements and theoretically designing a vehicle concept that would meet the Army's requirements. Four separate concepts were evaluated:

(a) Modifying the present M151 for the purpose of reducing cost by incorporating high-production commercial components, eliminating items or components where possible, and improving reliability of the vehicle by modifying components where statistical data indicate this to be desirable.

(b) Modifying the present commercially available vehicles such as the Jeep and the Scout to meet military requirements.

(c) Designing a new vehicle concept incorporating the best features of the present ¼-ton utility truck and the commercially available vehicles.

(d) Designing a vehicle concept having amphibious capabilities without compromising on land mobility and without substantially increasing vehicle cost.

The review indicated that the proposed vehicle would have to have a greater capability and more reliability than the present M151. In addition the vehicle would have floating or swimming capabilities in lieu of fording capabilities on the present M151. The M38 vehicle was developed in 1942, and many subsequent modifications were made prior to the development of the present M151 produced in 1959. The first and second flights of the present M151's were produced for approximately $3500 per unit. The third and present flights of M151's are being produced for $2442 per unit. The present QMR, in essence, states that the vehicle must be superior to the M151 at a lower unit cost stated to be $1900, which is $542 less than that of the present vehicle. It was determined that commercially available ¼-ton trucks could be purchased for $1900 but did not meet the vehicle's requirements. It was therefore required to evaluate various design tradeoffs to produce the most effective vehicle for its cost. The technical analysis that was made is reported in the next section. In following sections, cost is analyzed and a concept vehicle is synthesized.

Cost

Mission Reliability. The mission reliability of the proposed QMR cannot be statistically determined because reliability data are not available; therefore the cost of the requirement cannot be assessed.

It has been determined by the analysis of operational data that the present M151 has a reliability of 71 percent. The QMR requires a vehicle having a 95 percent reliability. This high reliability is unrealistic since it is not attainable in the present state of the art. The cost of this requirement as presently stated cannot be assessed.

A new realistic requirement for reliability should be made with a definition of its meaning.

Payload. Vehicles presently in the field have the capability of meeting the required payload. A vehicle that would meet the present QMR, or an austere vehicle, would also have this capability. Therefore cost is not affected by this requirement.

Inherent Floating Capability. The requirement of an inherent floating capability in inland waters without special preparation, provided this could be obtained within the overall vehicle cost objectives, cannot be met. The floating capability can be achieved for an increased cost of approximately $260. However, the incorporation of this capability was not recommended, since it would affect maintainability and the cost of the vehicles (see the section "Technical Analysis of the Vehicle").

Slopes with Payload. The requirement to negotiate a maximum grade of 60 percent with a given payload does not affect the cost of the vehicle. The maximum horsepower requirement does not occur at the maximum grade but at the vehicle's maximum speed. Therefore this requirement has no effect on cost (see tables and graphs on tractive effort in the section "Technical Analysis of the Vehicle").

Brake Stopping Power. The cost is not affected by this requirement, since the specified capability is available now throughout the automotive industry.

Cruising Range. The 300-mile-cruising-range requirement will increase the vehicle's cost by approximately $3. This additional cost would provide for a larger fuel tank.

Sustained Speeds on Level Roads. Maximum horsepower is required when performing at maximum speeds. Speed is therefore a factor that directly affects cost. A 30-hp engine will cost less than a 60-hp engine. The cost of a 30-hp engine, however, is not half that of a 60-hp engine, since the cost per

horsepower does not follow a lineal function. The present recommended engine has the capability to propel the vehicle at sustained speeds of 60 mph. This would achieve the required overall vehicle performance. Therefore this requirement does not increase the vehicle's cost.

30 Mph, 6 Percent Grade with Full Load and Towed Load. This requirement is accomplished when maximum vehicle speed is satisfied, and therefore no additional cost is effected.

Horsepower-to-Weight Ratio, 30 Hp/Ton Minimum. This requirement is fulfilled now and would have no effect on cost. Since the speed is a function of horsepower and the speed requirement is satisfied, the above requirement is automatically fulfilled. Either speed or horsepower/ton requirements, whichever is greater, should be listed in the QMR, but not both.

Wall-to-Wall Turning Radius of 18 Ft. This requirement is inherent in the present steering system and size of the vehicle. It has no effect on cost.

90 Percent Probability, Minor and Major Overhaul. The proposed QMR specification of a 90 percent probability of achieving 15,000 miles without minor and 25,000 miles without major overhaul or replacement of a major component is unrealistically high. The cost cannot be assessed.

Wide Liquid-Fuel Range. An engine with multifuel capabilities, such as the diesel or turbine, is many times more expensive than the gasoline engine. Not only are these engines more expensive, but compatible power-train components also would be more expensive. Therefore this requirement is not recommended (see the discussion of engine selection in the section "Technical Analysis of the Vehicle").

Storage Degradation. The cost of meeting the required limits on depot and field-storage degradation in ready rate is negligible provided that the vehicle is properly prepared for storage and that storage conditions are maintained within tolerable limits. Since the present M151 is capable of meeting specific storage degradation requirements, the new vehicle will also meet this requirement.

Airdroppability, Phase I. This requirement does not increase the cost of the vehicle since the requirements to withstand cross-country operation provide a vehicle that can also withstand airdropping.

Water Self-Propulsion up to 4 Mph. The desired requirement for self-propulsion over inland waterways at speeds up to 4 mph without special preparation cannot be met within the overall vehicle cost objectives. Self-propulsion up to 4 mph can be achieved by incorporating an auxiliary water propulsion device such as a propeller or hydrojet. To achieve a water speed capability up to 4 mph the vehicle would require true amphibian swimming capabilities and the incorporation of a full-length watertight buoyant hull. This capability can be accomplished at an increased cost of approximately $950; however, the incorporation of this capability is not recommended since it affects vehicle maintainability, ground clearance, and land mobility (see the discussion of swimming capabilities in the section "Technical Analysis of the Vehicle").

Compatibility with the Present ¼-ton Trailer. This requirement can be met for the cost of towing eye, which is approximately $7. The vehicle power train has this capability now.

Capability to Transport at Least Four Personnel Including Equipment. This requirement can be met by the addition of a rear seat at an increased cost of approximately $22.60.

Spare Tire. The provision for the stowage of a spare tire that will provide get-home capability can be incorporated at an approximate cost of $36.40. It will not occupy any vehicle cargo space and will be readily accessible when the vehicle is loaded.

Glove Compartment. A container to hold operation manuals, logbooks, and other forms can be incorporated adjacent to the transmission cover for a cost of approximately $12. The container located in the vehicle dash is not recommended because of the limited available space.

Lifting and Tie-Down Eyes. This requirement can be incorporated into the vehicle at a cost of approximately $6.75.

Turn Signals. This requirement increases the cost approximately $25. Turn signals are recommended to comply with state laws and for the safety of the vehicle and personnel (see the discussion of lighting in the section "Technical Analysis of the Vehicle").

Tire-Chain Clearance. This requirement can be incorporated at no additional cost. This is accomplished in the vehicle design phase by providing sufficient clearance in wheel-well areas.

24-v Military Electrical System, 60- to 70-amp Alternator. The cost of a Military Standard 24-v electrical system with a 60-amp alternator is approximately $71 more than the current military standard electrical system incorporated in the M151 (see the discussion of the electrical system in the section "Technical Analysis of the Vehicle").

Angles of Approach and Departure. This requirement can be met at no additional cost owing to the inherent design of the vehicle.

Four-Wheel Drive. This requirement is incorporated in the present M151 vehicles and therefore does not effect additional cost. However, should this requirement be deleted in favor of a two-wheel drive, a cost saving of approximately $125 can be realized. This is not recommended since it would greatly affect vehicle mobility.

Maximum Curb Weight of 2700 Lb. This requirement can be met with no additional cost. The three concepts shown in this study are all within the maximum weight limit.

Minimum Time between Scheduled Maintenance. This requirement has no effect on cost since the present M151 vehicle meets this requirement.

Failure Diagnosis. This requirement has no effect on cost since the present M151 vehicle meets this requirement.

Maximum Repair Time. This requirement has no effect on cost since the present M151 vehicle meets this requirement.

Arctic Kit, -25 to -65°F. Cost of the requirement is estimated at $290. It is recommended that this kit be provided to improve reliability and utility in arctic operation.

Personnel Heater, -25°F. This requirement is estimated to cost $125. This kit is recommended for use in conjunction with canvas or hardtop enclosures for personnel comfort.

Desert, +125°F. The design of a cooling system to efficiently cool an engine under desert condition requires a radiator with larger cooling capacity than required for normal operations. There is no cost increase in meeting this requirement, since the cooling requirements for a vehicle idling for a long period of time will satisfy this requirement.

Slave Receptacle. This requirement will increase the cost approximately $16 and is recommended for use in all vehicles to permit emergency starting by slaving to other vehicles for continued radio operation and cold weather starting (see the discussion of power analysis in the section "Technical Analysis of the Vehicle").

Communications Kit. The requirement to provide the space and the necessary mounting pads and structural members is estimated to cost $15. The power requirements will add $71 for the 60- to 70-amp alternator required (see the discussion of the generating system in the section "Technical Analysis of the Vehicle").

Light-Machinegun Kit. The capability of mounting the 7.62-mm (M60) machinegun is accomplished by the addition of members in the chassis and body. The cost of achieving this requirement is estimated to be $7.

Heavy Assault Weapons (HAW) Kit. The HAW weapon is presently under development, but the cost of mounting to meet this requirement cannot be determined at this time.

Target Unit Cost of $1900. This study has indicated that an austere vehicle can be produced for $1900, but it will not meet the required performance and physical characteristics of operational capability, reliability, and maintainability as expressed in the current QMR.

Cross-Country Mobility. The requirement that the vehicle possess equal or improved cross-country mobility characteristics over current standard ¼-ton trucks can be met with no increase in cost. This capability is inherent in the selection of similar power-train components, overall drive gear ratios, and chassis body design having comparable weights.

Fuel Economy. This requirement has not affected the cost, since the recommended engine is the same as specified in the M151. Therefore, fuel consumption would not be affected.

On-Vehicle Stowage of Vehicle Tools and Equipment. This requirement will add an estimated cost of $36. This stowage facility is recommended.

Windshield. A windshield capable of being folded or removed can be provided for an additional $5.50 over the cost of a standard windshield. This is a desirable feature and should be incorporated.

Transportability. The cost associated with the requirement for transportability of the proposed vehicle by rail, highway, ship, fixed-wing aircraft, and rotary-wing aircraft is negligible (see the discussion of transportability in the section "Technical Analysis of the Vehicle").

Vehicle Design with Respect to Seats and Controls. The cost of specifying seats to fit the 95 percentile man does not add materially to the cost of the vehicle. The requirement for an adjustable seat would cost an estimated $6 more than a nonadjustable seat. The cost of each seat is estimated at $25.

The cost of specifying controls to meet the human engineering characteristics does not add materially to the cost of the vehicle, since controls must be provided to perform control functions. Additional cost to the manufacturer is incurred during the design engineering.

Specifying displays and visual indicators to present information in the most meaningful form adds cost to the vehicle to the extent that gages, rather than warning lights, will be required. Other than design cost, the additional cost per vehicle is estimated at $10.

Effectiveness

Mission Reliability. The statistical analysis of maintenance data indicates a mission reliability of 71 percent. This is based on replacement rather than failure data. The specification of a mission reliability in the proposed QMR does not contribute to the effectiveness of the QMR.

Payload. This requirement assures the vehicle body will be designed to carry the required payload while maintaining or increasing its utility value and operational effectiveness.

Inherent Floating Capability. A vehicle having inherent floating capabilities does not greatly increase its effectiveness owing to the limited water speeds obtained through wheel propulsion only. A water speed of 4 mph is considered minimum to negotiate most rivers. In addition, vehicle mobility, entering and exiting, requires more thrust than is available by wheels only (see the section "Technical Analysis of the Vehicle").

Slopes with Payload. This requirement is essential to ensure mobility under cross-country operation. Engine selection was determined by the maximum speed requirement, which also meets the requirement of negotiating slopes with payload.

Brake Stopping Power. Vehicle brakes must be designed for maximum safety and durability. This requirement effectively influences the design criteria on which to base calculations to determine size, loads, pressure, and heat dissipation.

Cruising Range. This requirement can be appreciated during actual combat conditions when the vehicle mission may be beyond the 75-mile/day utilization. During combat the vehicle may be subjected to around-the-clock operations. Fuel capacity and vehicle range are of vital importance and should be increased whenever possible.

Sustained Speeds on Level Roads. This requirement is most important in selecting power-train components. Maximum vehicle speed determines the maximum horsepower requirement. The most desirable commercially available engine does not always meet exact requirements, and therefore the next higher rated engine must be selected. In this case the engine not only meets but exceeds the vehicle's requirements.

30 Mph, 6 Percent Grade with Full Payload and Towed Load. The vehicle design is not affected by this requirement. The power to satisfy this requirement is inherent in the power train that was selected, determined by the requirement to satisfy engine speed.

Wall-to-Wall Turning Radius of 18 Ft. The effectiveness of this requirement ensures adequate maneuvering capabilities.

90 Percent Probability, Minor and Major Overhaul. The requirement of a 90 percent probability of operating for 15,000 miles with only scheduled maintenance and 25,000 miles without major overhaul or replacement is unrealistic, and the effectiveness cannot be assessed.

Wide Liquid-Fuel Range. A diesel or turbine installation would require complete redesign of the vehicle. A diesel engine would be considerably heavier than a gasoline engine. This would have an effect on airdroppability and the floating or amphibious requirement. A turbine engine would weigh less, but a

compatible transmission for this engine would complicate the installation. In addition, fuel consumption would be considerably greater for the turbine engine.

Storage Degradation. The specified storage-degradation requirements will enhance the proposed vehicle ready rate and increase its military effectiveness. Primarily this vehicle, after having been subjected to periods of storage, will be physically capable of performing its mission with minimum effort and time.

Water Self-Propulsion up to 4 Mph. An amphibious capability with a water speed of 4 mph would enhance the vehicle's overall utility value. The greatly increased initial and support cost, however, plus the decrease in maintainability, decrease in land mobility, and adverse effect on good handling characteristics would degrade an important objective and effectiveness of the vehicle, since the simplicity of this type of vehicle must be maintained to ensure its effectiveness.

Compatibility with Present $\frac{1}{4}$-ton Trailer. This requirement affects the vehicle's maneuverability and power requirements. In this case a larger engine was not needed since the selected engine has more power than it actually required (see graphs in the section "Technical Analysis of the Vehicle").

Capacity to Transport at Least Four Personnel Including Equipment. The capability of transporting at least four personnel and equipment is a required asset to the vehicle. This ability broadens its scope of utility and would release vehicles for other required duties, thereby reducing the number of vehicles required to accomplish a given mission.

Spare Tire. This vehicle encounters many types of operating conditions in different environments. Because of its broad scope of usefulness it would unavoidably encounter a variety of sharp objects that could puncture the tires and disable the vehicle. A readily accessible spare tire would allow the personnel to accomplish their mission with a minimum of delay.

Glove Compartment. The effect of specifying a container to hold manuals and other forms ensures that a suitable container would be provided and space would be allocated in the vehicle. This has an effect on space utilization for other requirements.

Lifting and Tie-Down Eyes. The vehicle must have the capability of being easily transportable by rail, sea, and air, to all theaters of operation. Built-in accommodations for lifting and tie-down decreases the time and manpower requirements to accomplish this task.

Turn Signals. The incorporation of turn signals has little effect on performance or safety of the vehicle when used in temperate zones where it is normally operated without canvas or hard-top enclosures, and hand signals are equally as effective as turn signals. However, to meet State law requirements and to provide for safety of the operating personnel when driving with the enclosure kits, turn signals are recommended. The turn-signal requirement involves the incorporation of a relay box and a turn-signal control.

Tire-Chain Clearance. Adequate clearance in the wheel well is essential for additional traction devices such as tire chains that may be required during adverse mobility conditions.

24-v Military Electrical System, 60- to 70-amp Alternator. The effectiveness of specifying a military standard electrical system that is fully radio suppressed and waterproof with a 60- to 70-amp alternator ensures that the components will have acceptable reliability and durability. The vehicle will

have the capability of permitting radio communications both on and in the immediate area while the vehicle is operating. The larger generating capacity provides the capability of using winterization, personnel heater, communication, or future kits without the addition of an auxiliary alternator kit (see the subsection "Power Analysis" in the section "Technical Analysis of the Vehicle").

Angles of Approach and Departure. The 60- and 45-deg angles of approach and departure, respectively, are essential to the mobility requirements of a vehicle during severe cross-country operations. This requirement is particularly effective in terrain where hills and ditches are encountered.

Four-Wheel Drive. This requirement is essential for cross-country operations. Without this feature, mobility, maneuverability, and the vehicle's effectiveness would be greatly reduced.

Maximum Curb Weight of 2700 Lb. This requirement could affect the vehicle's performance and airlift capabilities. The proposed vehicle would be within the required maximum weight limits.

Minimum Time between Scheduled Maintenance. This requirement can be achieved without decreasing the vehicle's effectiveness.

Failure Diagnosis. This requirement can be achieved without decreasing the vehicle's effectiveness.

Maximum Repair Time. This requirement can be achieved without decreasing the vehicle's effectiveness.

Arctic Kit, -25°F to -65°F. The effectiveness of specifying an arctic kit, -25 to -65° F, ensures that mounting provisions and power requirements will be provided in the vehicle and that the vehicle will have the capability of operating in a cold environment.

Personnel Heater, -25°F. The effect of specifying a personnel heater kit for temperatures to -25°F ensures that mounting space and power requirements will be provided in all vehicles to accept the kits. This kit would provide personnel comfort and would not materially affect the vehicle's reliability.

Desert, +125°F. The importance of this requirement affects the capacity of the cooling system to prevent engine overheating and the design of a carburetor to prevent vapor lock.

Slave Receptacle. This requirement would ensure that the vehicle would have the capability to accept a kit when provided.

Communications Kit. This requirement ensures that the vehicle would be capable of accepting communications kits. The body would incorporate additional structural members and space would be provided. In addition, provisions for adequate electrical power would be assured.

Light-Machinegun Kit. This requirement would increase combat effectiveness against troops, low-flying aircraft, and guerrilla attacks.

Heavy Assault Weapons (HAW) Kit. This requirement would provide a mobile weapons platform for any of the HAW and would provide additional effectiveness.

Target Unit Cost of $1900. This requirement would definitely limit the vehicle's effectiveness under combat conditions (see the section "Austere Vehicle").

Fuel Economy. The effectiveness of a vehicle can be measured by its cruising range. Good fuel economy will increase the vehicle's range. Engines considered in this horsepower class have comparable fuel economy.

On-Vehicle Stowage. The effect of specifying stowage provisions for vehicular tools, equipment, and individual weapons for the driver ensures that suitable containers or brackets would be designed and provided with the vehicle.

Inclement-Weather Kits. This requirement ensures that suitable kits would be developed and that necessary mounting features would be designed into the vehicle. The extent of vehicle or personnel protection was not specified.

Human Engineering Characteristics. The effect of specifying this requirement with respect to seating, controls, control movements, visual indicators, and displays will be to ensure consideration during vehicle design. This item is subject to interpretation and may not be optimum in the initial design. To provide specific information for these items is impractical since the final determination can be made only after the construction of a prototype.

Interrelations between Requirements

Mission Reliability. This requirement can be satisfied if an acceptable level of reliability of all the components and systems can be assured.

Payload. This requirement affects all the major components in the power-train system, suspension system, chassis, and body. All the systems have the capability of accepting this payload.

Inherent Floating Capability. The desired floating capability is directly related to the mobility requirements and adversely affects cost, weight, and mobility.

Slopes with Payload. Provision of the required torque affects the structural components, brakes, engine oil pan and carburetor, and the gear ratios in the transmission.

Brake Stopping Power. This requirement is directly related to the vehicle's payload. This payload then becomes a part of the gross vehicle weight, which must be known in order to select the brakes. Therefore as the payload increases, the capability of the brakes must increase. The reverse is also true.

Cruising Range. This requirement is directly related to the capacity of the fuel tank and is inversely affected by increased vehicle weight. In addition the size and weight of a full fuel tank may affect the design of other components.

Sustained Speeds on Level Roads.
30 Mph, 6 Percent Grade.
Horsepower-to-Weight Ratio, 30 Hp/Ton Minimum.
Fuel Economy.
Compatibility with $\frac{1}{4}$-ton Trailer.
Wide Liquid-Fuel Range.

All these requirements are closely related to each other and are directly related to the payload requirements. These factors influence the vehicle's performance and the selection of power train components (see the subsection "Power Train" in the section "Technical Analysis of the Vehicle").

Wall-to-Wall Turning Radius of 18 Ft. This requirement is related to vehicle size and configuration.

90 Percent Probability, Minor and Major Overhaul. The requirement of operating 15,000 miles without minor and 25,000 miles without major overhaul is directly related to the vehicle's reliability.

Storage Degradation. This requirement is related to the vehicle's reliability and vehicle components that may be subject to corrosion or oxidation where high ozone content is present.

Airdroppability, Phase I. This requirement is related to the vehicle's cross-country mobility, weight, and payload capacity. It has an effect on the chassis, suspension system, body, and the location of the lifting and tie-down eyes, which are used to secure the vehicle during transport and for parachute attachment when air dropped.

Water Self-Propulsion, up to 4 Mph. This requirement is directly related to the mobility requirements that provide for capability of making water crossings, but adversely affects mobility on land. Cost, weight, and maintainability objectives are adversely affected. A completely new vehicle design program would be required to include this capability.

Capability to Transport at Least Four Personnel Including Equipment. This requirement is related to the requirement of a two-man crew plus rated payload. This requirement must be considered in the original design phase so that the rear seat may be added by the use of seat brackets.

Spare Tire. This requirement is related to the vehicle's reliability, weight, and cost.

Turn Signals. This requirement is related to the vehicle's electrical power requirements, human engineering, safety of personnel, and cost.

Tire-Chain Clearance. This requirement is related to the vehicle's mobility requirements.

24-v Electrical System. This requirement is related to mission reliability and power requirements for various kits.

Angles of Approach and Departure. This requirement is related to the vehicle's mobility.

Four-Wheel Drive. This requirement is related to cross-country mobility and vehicle cost.

Maximum Curb Weight of 2700 Lb. This requirement is related to the vehicle's mobility, fuel economy, transportability, and cost.

Minimum Time between Scheduled Maintenance. This requirement is directly related to the vehicle's reliability and cost.

Failure Diagnosis. This requirement is directly related to the vehicle's reliability and cost.

Maximum Repair Time. This requirement is directly related to the vehicle's reliability and cost.

Arctic Kits, -25 to -65°F. This requirement is related to mission reliability by enabling the vehicle to operate under conditions of severe cold. It is interrelated with electrical power requirements.

Personnel Heater, -25°F. This requirement is related to the vehicle's electrical power requirements.

Desert, +125°F. This requirement is not related to any of the other requirements with the exception of cost.

Slave Receptacle. This requirement is related to mission reliability and electrical power requirements.

Communications Kit. This requirement is related to mission reliability and the 24-v radio-suppressed electrical system.

Light-Machinegun Kit. This requirement is related to the crew's safety, vehicle stability, and human engineering.

Heavy Assault Weapons (HAW) Kit. This requirement is related to the crew's safety, vehicle stability, and human engineering.

Target Cost of $1900. This requirement is either directly or indirectly related to all other requirements stated in the QMR.

Human Engineering. This requirement is related to the vehicle's weight, controls, visual indicators, and all kits.

Inclement-Weather Kits. This requirement is related to the mission reliability.

On-Vehicle Stowage. This requirement is related to mission reliability.

Windshield Design. This requirement is related to human engineering, personnel safety, inclement-weather protection, and transportability.

Transportability. This requirement is related to vehicle attachments, weight, and physical size.

Cross-Country Mobility. This requirement is related to the selection of the power-train components such as the transmission, transfer case, drive line, differential, suspension system, controls, and chassis-body design. In addition, it is related to maintenance, mission reliability, weight, floating capability, and vehicle cost.

Cost of Spare Parts, Rebuild, and Maintenance

The cost of spare parts for a vehicle as described in the current QMR, but without floating or swimming capabilities, is estimated to be $504. This cost is based on supplying a complete set of spare components for every five vehicles. If the floating or amphibious characteristics are incorporated the spare parts cost will increase by approximately $140. This is because of the added complexity of the power train and the marine propulsion system equipment.

The rebuild and maintenance cost for vehicles as described in the current QMR, but without the floating or swimming capabilities, is estimated to be the same as that of the present M151. If floating or amphibious characteristics are incorporated, the rebuild and maintenance cost is estimated to increase by approximately 25 percent. This is due to the limited or confined space as a result of incorporating a watertight hull or body, thereby increasing the maintenance time required and the additional components required for amphibious capabilities, such as bilge pump, more complex controls, extra universal joints for land drive shafts and seals, and marine drive shaft, bearings, seals, and propeller assembly (or hydrojet assembly).

Trade-Off Design Characteristics

The design characteristics for each individual requirement stated in the current QMR were analyzed with respect to trade-off design. No trade-off design was necessary except in the areas of floatability, 4-mph self-propelled swimming capability, and the capability of operating on a wide range of liquid petroleum fuel. The current QMR also states that it is desirable that the vehicle possess these characteristics provided they could be obtained within the overall cost objectives. Our cost analysis also established that these characteristics could not be obtained within the overall vehicle cost objectives and therefore with these exceptions, no trade-off design characteristics were affected since all other requirements in the proposed QMR were either met or exceeded by the recommended vehicle.

TECHNICAL ANALYSIS OF THE VEHICLE

POWER-TRAIN REQUIREMENTS

The power-train section discusses the basic vehicle performance requirements and establishes through performance calculations the range of power-train components that will meet the desired vehicle performance specifications.

To make these calculations, certain design criteria had to be established in order to find the vehicle performance limitations for an average performance condition. These criteria fall within the standard performance calculation practices and provide sufficient accuracy:

(a) The coefficient of rolling resistance expresses effects of the interdependent physical properties of ti and ground influenced by the inflation pressure and vehicle speed. For the average condition the coefficient of rolling resistance is often expressed as a linear function of speed. In this calculation a constant value of 35 lb/ton was chosen.

(b) Air resistance of a moving vehicle is a function of body shape, projected frontal area, air density, and the velocity of body relative to air. If small slow-moving vehicles are being discussed, air resistance for all practical purposes can be neglected.

Drag resistance, cooling, ventilating air flow, and air friction on the surface of the body are the four factors that express the coefficient of air resistance for which standard Society of Automotive Engineers (SAE) values were used.

Changes in air density at higher altitudes were neglected. Normal atmospheric conditions of 60°F and 29.9 in. Hg were assumed.

(c) The power-train resistance, commonly called "power-train efficiency," is not a motion-resisting force in the same sense as rolling, grade, or air resistance. It is a value (found experimentally on dynamometer tests) that expresses power lost between engine output and drive wheels because of friction and heat. Power-train efficiencies, excluding the engine, are first gear, 79 percent; second gear, 81 percent; third gear, 84 percent; and fourth gear, 86 percent.

Design calculations were based on efficiency values of established power trains of similar configuration.

Using these assumed values for an average performance condition and vehicle performance requirements listed in the QMR, calculations were made to reestablish the vehicle's power-train requirements. Table 2 shows the characteristics of the recommended vehicle.

Calculations for the tractive effort to overcome rolling resistance and air resistance are presented in Tables 3, 4, and 5.

TABLE 2

Characteristics of the Recommended Vehicle[a]

QMR par no.	Performance characteristics	Requirement
7.a(7)	Range, miles	300
	Highway, %	30
	Secondary roads, %	40
	Cross-country, %	30
	Battlefield day performance (average use/day), miles	75
	Idling, %	40
	Cross-country, %	40
	Secondary roads, %	20
7.a(5)	Gradeability, %	
	Forward slope, maximum, %	60
	Side slope, maximum, %	40
7.a(8)	Speeds, mph	
	Dry, level, hard surface	
	Sustained	60
	Minimum	2.5
7.a(9)	Speed, mph	
	6% forward slope, dry, full payload plus towed load of 1500 lb, maintained	30
7.a(10)	Horsepower-to-weight ratio, minimum, hp/ton GVW	44
8.a(1)	Payload in addition to 2 personnel, (400 lb)	500
	Basic vehicle weight, lb	2300
	Gross vehicle weight, lb (2300 + 400 + 500)	3200

[a]The characteristics were taken from Sec IV of the QMR (App A).

TABLE 3

Required Tractive Effort (TE)

Gross vehicle weight (GVW) = 3200 lb
Rolling resistance (f) = 35 lb/ton = 0.0175
Grade angle in degrees = Θ

$$\frac{\text{Grade angle in percent}}{100} = \operatorname{Tan}\Theta$$

Grade, %	Θ	Tan Θ	Sin Θ	Cos Θ	$f \times$ Cos Θ	$f \times$ Cos $\Theta \times$ Sin Θ	TE[a], lb
0	0	0	0	1.000	0.0175	0.0157	56
6	3° 26'	0.060	0.0598	0.998	0.01746	0.07726	361[b]
10	5° 43'	0.100	0.0996	0.995	0.0174	0.0174	374
20	11° 19'	0.200	0.196	0.981	0.01715	0.21315	682
30	16° 42'	0.300	0.287	0.958	0.01677	0.30377	973
40	21° 48'	0.400	0.371	0.928	0.01624	0.33724	1240
50	26° 34'	0.500	0.447	0.894	0.01564	0.46264	1480
60	31°	0.600	0.515	0.857	0.01500	0.530	1700

[a]TE = GVW ($f \times$ Cos Θ + Sin Θ), lb.
[b]With towed load of 1500 lb.

Preliminary Engine Selection

A tentative engine selection was made based on preceding net engine output horsepower requirement calculations. Since the engine now installed in the M151 falls within these requirements, the characteristics of this engine (shown in Table 6 and Fig. 1) were used for further calculations.

A final engine selection at this stage was premature, since all the facts to make this decision were not known. Meeting the engine output power requirements did not necessarily indicate the correctness of the choice. A transmis-

TABLE 4

Air Resistance[a, 1]

(R_a = Air resistance, lb[b]; C_a = Coefficient of air resistance; A = Projected frontal vehicle area, ft^2; V = Vehicle speed, mph)

V	$\left(\frac{V}{10}\right)^2$	$0.26 \times C_a \times A$	R_a, lb
0	0	4.425	0
5	0.25	4.425	1.11
10	1	4.425	4.25
20	4	4.425	17.70
30	9	4.425	39.80
40	16	4.425	70.80
50	25	4.425	110.60
60	36	4.425	159.30
70	49	4.425	216.80

[a]Changes in air density at higher altitudes have been neglected in this calculation. Standard atmospheric conditions (60°F and 29.9 Hg) were used.

[b]$R_a = 0.26\, C_a \times A \times \left(\frac{V}{10}\right)^2$ lb.

[c]$A = 0.9 \times$ vehicle height $\times$ wheel tread.

$$A = \frac{0.9 \times 71 \times 48}{12 \times 12} = 21.3 \text{ ft}^2.$$

TABLE 5

Net Engine Horsepower Requirements

(Tire rolling radius, r = 15 in.)

Gear (1)	Grade, % (2)	Vehicle speed (3)	Tractive effort (4)	Air resistance (5)	Total resistance, lb[a] (6)	Power-train efficiencies, % (7)	Wheel rpm[b] (8)	Wheel torque[c] (9)	Required engine hp[d] (10)
Low	60	5	1700	1.11	1701.11	79	56	2126	28.7
High	0	60	56	159.30	215.3	86	672	2691	40

[a]Col 6 = Col 4 + col 5.

[b]Col 8 = $5280 \times 12/2 \times 15 \times 60 \times \pi \times$ col 3 = $11.2 \times$ col 3.

[c]Col 9 = $r \times$ col 6/12 = $1.25 \times$ col 6.

[d]Col 10 = col 8 $\times$ col 9/col 7 $\times$ 5250.

TABLE 6

Engine Characteristics

(Engine = Army Part No. 8754411; bore = 3.875 in. diameter; stroke = 3 in.; displacement = 141.5 in.; and compression ratio = 7.5 : 1)

Rpm	Gross power, hp	Gross torque, ft-lb	Net power, hp	Net torque, ft-lb
750	18.80	107.20	13.15	92.00
1000	22.90	120.00	19.60	103.00
1500	38.85	135.90	33.30	116.50
1700	44.80	138.90	38.50	119.00
2000	51.90	136.50	44.50	117.00
2500	61.40	130.00	52.60	111.50
3000	68.10	119.00	58.30	102.00
3500	71.00	105.40	60.80	91.40
4000	70.40	92.10	60.20	78.00

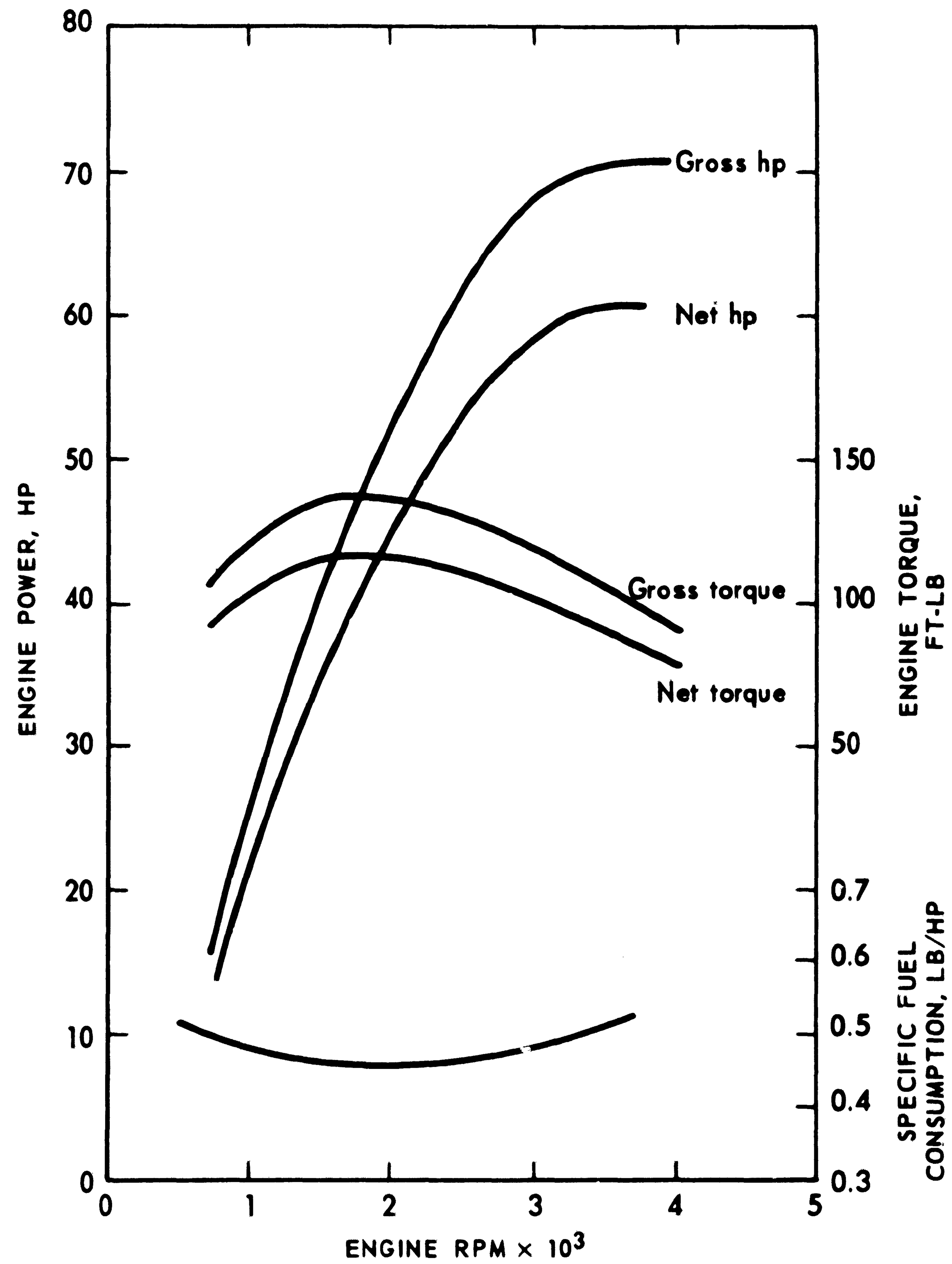

Fig. 1—Engine Performance Curves

Army Part No. 8754411

71 Gross hp @ 3900 rpm; 138 ft-lb @ 800 rpm

sion and rear-axle selection had to be made before making the final match to satisfy not only the demand for power but also the need for speed.

Overall Required Power-Train Reduction

The overall required reduction ratios were found from data taken from engine curves of the tentatively selected engine.

In establishing transmission ratios two major criteria had to be considered: (a) maximum speed requirements for high-gear reduction and (b) maximum torque requirements for low-gear reduction.

(a) Overall high-gear reduction ratio

Characteristic	Value
Maximum vehicle speed, mph	60
Tire rolling radius, in.	15
Maximum available engine rpm	4000

Wheel rpm = $60 \times 5280 \times 12/60 \times 2 \times 15 \times \pi$ = 672
High-gear ratio = 4000/672 = 5.95:1

(b) Overall low-gear reduction ratio

Characteristic	Value
Maximum motion resisting force F_r, lb	1700 + 1.11 = 1701.1
Tire rolling radius, in.	15
Power-train efficiency first gear, %	79

Wheel torque, ft-lb = $1701.1 \times 15/12$ = 2126
First gear ratio = wheel torque/maximum engine torque × efficiency
= $2126/119 \times 0.79$
Second gear ratio = 22.6:1

Transmission Discussion

Establishment of the two main transmission ratios now permits further calculations and discussions that will disclose more detailed information concerning size, power input and output, efficiencies, and number of speeds required. With high and low gear ratio known, the overall spread was figured:

$$\text{Low/high} = 22.6/5.95 = 3.8 = \text{spread}$$

A spread is defined as the ratio from one gear to the next higher, which in common practice is held close to a 2 to 1 ratio. This factor defines the number of gears or speed requirements.

Three-Speed Transmission Ratios. The required overall gear ratios for a three-speed transmission are

$$\underbrace{\text{low} - \text{second}}_{1}\underbrace{\;-\;\text{high}}_{2}$$

If the spread between gears is kept the same the individual spread is the square root of the overall spread.

$$\sqrt{3.8} = 1.95$$

The overall ratios, transmission and rear axle, are low gear, 22.6; second gear, 22.6/1.95 or 11.6; and high gear, 5.95.

It is the usual practice to make the transmission high-gear reduction a 1 to 1 ratio, taking all required reduction in the rear axle. This reduction as a general rule should lie between the ratios of 3 to 1 and 6 to 1. In observing this rule the rear-axle ratio was therefore established:

$$\text{Rear-axle ratio} = 5.95{:}1$$

With rear-axle ratio known, the transmission ratios are low, 22.6/5.95 or 3.8 to 1; second, 11.6/5.95 or 1.95 to 1; and high, 5.95/5.95 or 1 to 1.

If too great a spread is chosen (going from a four- to a three-spread transmission, for instance) optimum vehicle performance in mid-spread ranges is decreased. Although an engine matched with a four-speed transmission could be running at lower speeds in third gear, the same engine with a three-speed transmission must operate at much higher speeds in second gear to reach the same transmission output speed.

Not all engines that fall within the power and speed requirements are suited for a match with a three-speed transmission, because not all engines are built to run constantly at high speeds.

An internal-combustion engine characteristically develops low torque at engine-idle rpm, increasing to maximum engine torque at medium engine rpm and constantly decreasing torque with increasing engine rpm. Therefore more effective engine response is obtained by operating at lower engine speeds on the low side of the power curve with power to spare than by passing the power peak running at higher engine rpm but with steadily decreasing power.

If a three-speed transmission is selected it must be matched with a two-speed transfer box to obtain the desired step-up ratios. This would then give a wider speed range and smoother power flow. After a thorough study and comparison of commercially available components, it was felt that this design would not provide any advantage in design or cost over an existing four-speed transmission.

Four-Speed Transmission Ratios. The overall transmission spread is the same as for the three-speed transmission, since the requirements for high and low gear reductions remain the same. Overall transmission spread is 3.8, and the number of spreads is

$$\underbrace{\text{low} \;-\; \text{second}}_{1}\;\underbrace{-\;\text{third}}_{2}\;\underbrace{-\;\text{fourth}}_{3}$$

If the spread is the same between gears the individual spread equals the cube root of the overall spread.

$$\sqrt[3]{3.8} = 1.56, \text{ and low gear} = 3.8 : 1$$
$$\text{Second gear} = 3.8/1.56 = 2.44 : 1$$
$$\text{Third gear} = 2.44/1.56 = 1.56 : 1$$
$$\text{Fourth gear} = 1.56/1.56 = 1 : 1$$

Required overall ratios for the transmission and rear axle are

Rear axle	= 5.95 : 1		
Low gear	= 5.95 × 3.8	=	22.6 : 1
Second gear	= 5.95 × 2.44	=	14.5 : 1
Third gear	= 3.95 × 1.56	=	9.3 : 1
Fourth gear	= 5.95 × 1	=	5.95 : 1

Desired Vehicle Performance Characteristics and Tractive Force Diagram

Calculations were made for (a) three-speed transmission with single gear transfer case and (b) four-speed transmission with single gear transfer case. Results of these calculations are shown in Tables 7 to 18 and Figs. 2 to 4.

These tables and diagrams show calculated values of vehicle motion resisting forces from 0 to 60 percent grade, which were plotted against vehicle speeds.

Superimposed on these curves are additional curves representing the performance for each transmission gear for different speeds on various grades. The desired vehicle performance is depicted by a single heavier-drawn curve connecting the desired characteristic points listed in the QMR.

TABLE 7

Desired Vehicle Performance

Grade, %	Speed, mph	T_e, lb	R_a, lb	F_r[a], lb
60	5	1700	1.11	1701.11
6	30	361	39.80	400.80
0	60	56	159.30	215.30

[a]F_r = Tractive effort + air resistance = total motion resisting force.

TABLE 8

Available Tractive Effort and Speed, First Gear, Three-Speed Transmission

(Overall reduction = 22.6:1; power-train efficiency, excluding engine = 79 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	33.2	1643	8.69	1314	2.96
1000	103	19.6	44.3	1840	15.5	1472	3.95
1500	116.5	33.3	66.4	2080	26.3	1664	5.93
1700	119	38.5	75.3	2125	30.2	1700	6.73
2000	117	44.5	88.5	2090	35.2	1672	7.90
2500	111.5	52.6	110.6	1990	41.6	1592	9.27
3000	102	58.3	132.8	1883	46.0	1458	11.86
3500	91.4	60.8	155.0	1634	48.1	1307	13.85
4000	79	60.2	177.0	1411	47.6	1128	15.80

[a]Col 4 = $\frac{\text{Col 1}}{\text{reduction}} = \frac{\text{Col 1}}{22.6}$.

[b]Col 5 = Col 2 × reduction × efficiency = Col 2 × 22.6 × 0.79 = Col 2 × 17.86.

[c]Col 6 = Col 3 × efficiency = Col 3 × 0.79.

[d]Col 7 = Col 5 × $\frac{12}{r}$ = Col 5 × $\frac{12}{15}$ = Col 5 × 0.8.

[e]Col 8 = Col 4 × $\frac{2 \times 15 \times \pi \times 60}{12 \times 5280}$ = Col 4 × 0:0893.

TABLE 9

Available Tractive Effort and Speed, Second Gear, Three-Speed Transmission

(Overall reduction = 11.6:1; power-train efficiency, excluding engine = 83 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	65	886	9.14	708	5.80
1000	103	19.6	86	993	16.25	795	7.68
1500	116.5	33.3	129	1122	27.81	898	11.53
1700	119	38.5	146	1147	31.92	918	13.05
2000	117	44.5	172	1128	36.90	903	15.37
2500	111.5	52.6	216	1074	43.60	860	19.30
3000	102	58.3	258	983	48.40	787	23.05
3500	91.4	60.8	302	881	50.50	705	26.95
4000	79	60.2	345	762	50.00	609	30.80

[a]Col 4 $= \frac{\text{Col 1}}{\text{reduction}} = \frac{\text{Col 1}}{11.6}$.

[b]Col 5 = Col 2 × reduction × efficiency = Col 2 × 11.6 × .83 = Col 2 × 9.63.

[c]Col 6 = Col 3 × efficiency = Col 3 = .83.

[d]Col 7 $=$ Col 5 $\times \frac{12}{r} =$ Col 5 $\times \frac{12}{15} =$ Col 5 × 0.8.

[e]Col 8 $=$ Col 4 $\times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} =$ Col 4 × 0.0893.

TABLE 10

Available Tractive Effort and Speed, Third Gear, Three-Speed Transmission

(Overall reduction = 5.95:1; power-train efficiency, excluding engine = 86 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	126	471	10.5	377	11.25
1000	103	19.6	168	527	16.85	422	15.50
1500	116.5	33.3	252	594	28.65	475	22.50
1700	119	38.5	286	609	33.1	487	25.50
2000	117	44.5	336	598	38.3	479	30.10
2500	111.5	52.6	420	570	45.2	457	37.50
3000	102	58.3	504	522	50.1	418	45.00
3500	91.4	60.8	588	467	52.4	375	52.50
4000	79	60.2	572	404	51.8	324	60.00

[a]Col 4 $= \frac{\text{Col 1}}{\text{reduction}} = \frac{\text{Col 1}}{5.95}$.

[b]Col 5 = Col 2 × reduction × efficiency = Col 2 × 5.95 × 0.86 = Col 2 × 5.12.

[c]Col 6 = Col 3 × efficiency = Col 3 × 0.86.

[d]Col 7 $=$ Col 5 $\times \frac{12}{r} =$ Col 5 $\times \frac{12}{15} =$ Col 5 × 0.8.

[e]Col 8 $=$ Col 4 $\times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} =$ Col 4 × 0.0893.

TABLE 11

Tractive Effort and Speed, First Gear, Four-Speed Transmission, Selected Ratio

(Overall reduction = 22.6:1; power-train efficiency, excluding engine = 79 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	33.2	1643	8.69	1314	2.96
1000	103	19.6	44.3	1840	15.5	1472	3.95
1500	116.5	33.3	66.4	2080	26.3	1664	5.93
1700	119	38.5	75.3	2125	30.2	1700	6.73
2000	117	44.5	88.5	2090	35.2	1672	7.90
2500	111.5	52.6	110.6	1990	41.6	1592	9.87
3000	102	58.3	132.8	1823	46.0	1458	11.86
3500	91.4	60.8	155.0	1634	48.1	1307	13.85
4000	79	60.2	177.0	1411	47.6	1128	15.80

[a]Col 4 = $\frac{\text{Col 1}}{\text{reduction}} = \frac{\text{Col 1}}{22.6}$.

[b]Col 5 = Col 2 × reduction × efficiency = Col 2 × 22.6 × 0.79 = Col 2 × 17.86.

[c]Col 6 = Col 3 × efficiency = Col 3 × 0.79.

[d]Col 7 = Col 5 × $\frac{12}{r}$ = Col 5 × $\frac{12}{15}$ = Col 5 × 0.8.

[e]Col 8 = Col 4 × $\frac{2 \times 15 \times \pi \times 60}{12 \times 5280}$ = Col 4 × 0.0893.

TABLE 12

Tractive Effort and Speed, Second Gear, Four-Speed Transmission, Selected Ratio

(Overall reduction = 14.5:1; power train efficiency, excluding engine = 81 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	51.75	1080	8.91	864	4.63
1000	103	19.6	69.0	1210	15.90	968	6.15
1500	116.5	33.3	103.5	1370	27.00	1103	9.25
1700	119	38.5	117.2	1398	31.20	1118	10.50
2000	117	44.5	138.0	1375	36.05	1100	12.50
2500	111.5	52.6	172.5	1311	42.60	1049	15.50
3000	102	58.3	207.0	1198	47.20	958	18.50
3500	91.4	60.8	241.0	1073	49.30	858	21.50
4000	79	60.2	276.0	928	48.80	742	24.65

[a]Col 4 = $\frac{\text{Col 1}}{\text{reduction}} = \frac{\text{Col 1}}{14.5}$.

[b]Col 5 = Col 2 × reduction × efficiency = Col 2 × 14.5 × 0.81 = Col 2 × 11.75.

[c]Col 6 = Col 3 × efficiency = Col 3 × 0.81.

[d]Col 7 = Col 5 × $\frac{12}{r}$ = Col 5 × $\frac{12}{15}$ = Col 5 × 0.8.

[e]Col 8 = Col 4 × $\frac{2 \times 15 \times \pi \times 60}{12 \times 5280}$ = Col 4 × 0.0893.

TABLE 13

Tractive Effort and Speed, Third Gear, Four-Speed Transmission, Selected Ratio

(Overall reduction = 9.3:1; power train efficiency, excluding engine = 84 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	80.6	718	10.8	574.4	7.2
1000	103	19.6	107.5	805	16.5	644.0	9.6
1500	116.5	33.3	161.5	910	28.0	728.0	14.4
1700	119	38.5	183.0	930	32.4	744.0	16.2
2000	117	44.5	215.0	915	37.4	732.0	19.2
2500	111.5	52.6	269.0	871	44.2	696.8	24.0
3000	102	58.3	323.0	797	49.0	637.6	29.8
3500	91.4	60.8	376.5	714	51.1	571.2	33.6
4000	79	60.2	430.0	617	50.6	493.6	38.4

[a] $\text{Col } 4 = \frac{\text{Col } 1}{\text{reduction}} = \frac{\text{Col } 1}{9.3}$.

[b] Col 5 = Col 2 × reduction × efficiency = Col 2 × 9.3 × 0.84 = Col 2 × 7.82.

[c] Col 6 = Col 3 × efficiency = Col 3 × 0.84.

[d] $\text{Col } 7 = \text{Col } 5 \times \frac{12}{r} = \text{Col } 5 \times \frac{12}{15} = \text{Col } 5 \times 0.8$.

[e] $\text{Col } 8 = \text{Col } 4 \times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} = \text{Col } 4 \times 0.0893$.

TABLE 14

Tractive Effort and Speed, Fourth Gear, Four-Speed Transmission, Selected Ratio

(Overall reduction = 5.95:1; power-train efficiency, excluding engine = 86 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effect, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	126	471	10.5	377	11.25
1000	103	10.6	168	527	16.85	422	15.50
1500	116.5	33.3	252	594	28.65	475	22.50
1700	119	38.5	286	609	33.1	487	25.50
2000	117	44.5	336	598	38.3	479	30.10
2500	111.5	52.6	420	570	45.2	457	37.50
3000	102	58.3	504	522	50.1	418	45.00
3500	91.4	60.8	588	467	52.4	375	52.50
4000	79	60.2	672	404	51.8	324	60.00

[a] $\text{Col } 4 = \frac{\text{Col } 1}{\text{reduction}} = \frac{\text{Col } 1}{5.95}$.

[b] Col 5 = Col 2 × reduction × efficiency = Col 2 × 5.95 × 0.86 = Col 2 × 5.12.

[c] Col 6 = Col 3 × efficiency = Col 3 × 0.86.

[d] $\text{Col } 7 = \text{Col } 5 \times \frac{12}{r} = \text{Col } 5 \times \frac{12}{15} = \text{Col } 5 \times 0.8$.

[e] $\text{Col } 8 = \text{Col } 4 \times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} = \text{Col } 4 \times 0.0893$.

TABLE 15

Tractive Effort and Speed, First Gear, Four-Speed Transmission with Commercially Available Power-Train Components

(Overall reduction = 24.8; = power-train efficiency, excluding engine = 79 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	30.2	1804	8.69	1442	2.7
1000	103	19.6	40.3	2015	15.48	1616	3.6
1500	116.5	33.3	60.4	2283	26.31	1826	5.4
1700	119	38.5	68.5	2330	30.41	1866	6.11
2000	117	44.5	80.6	2293	35.15	1835	7.19
2500	111.5	52.6	100.7	2186	41.55	1747	8.98
3000	102	58.3	121.0	1999	46.06	1598	10.80
3500	91.4	60.8	141.2	1790	48.03	1433	12.62
4000	79	60.2	161.4	1548	47.56	1238	14.41

[a] $\text{Col } 4 = \frac{\text{Col } 1}{\text{reduction}} = \frac{\text{Col } 1}{24.8}$.

[b] Col 5 = Col 2 × reduction × efficiency = Col 2 × 24.8 × 0.79 = Col 2 × 19.6.

[c] Col 6 = Col 3 × efficiency = Col 3 × 0.79.

[d] $\text{Col } 7 = \text{Col } 5 \times \frac{12}{r} = \text{Col } 5 \times \frac{12}{15} = \text{Col } 5 \times 0.8$.

[e] $\text{Col } 8 = \text{Col } 4 \times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} = \text{Col } 4 \times 0.0893$.

TABLE 16

Tractive Effort and Speed, Second Gear, Four-Speed Transmission with Commercially Available Power-Train Components

(Overall reduction = 15.75:1; power-train efficiency, excluding engine = 81 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	47.7	1174	8.91	939	4.26
1000	103	19.6	63.5	1314	15.88	1051	5.67
1500	116.5	33.3	95.3	1487	26.97	1190	8.51
1700	119	38.5	107.9	1518	31.18	1214	9.64
2000	117	44.5	127.0	1493	36.05	1194	11.34
2500	111.5	52.6	158.7	1423	42.60	1138	14.17
3000	102	58.3	190.5	1302	47.22	1042	17.01
3500	91.4	60.8	222.2	1166	49.25	933	19.84
4000	79	60.2	254.0	1008	48.76	806	22.68

[a] $\text{Col } 4 = \frac{\text{Col } 1}{\text{reduction}} = \frac{\text{Col } 1}{15.75}$.

[b] Col 5 = Col 2 × reduction × efficiency = Col 2 × 15.75 × 0.81 = Col 2 × 12.76.

[c] Col 6 = Col 3 × efficiency = Col 3 = 0.81.

[d] $\text{Col } 7 = \text{Col } 5 \times \frac{12}{r} = \text{Col } 5 \times \frac{12}{15} = \text{Col } 5 \times 0.8$.

[e] $\text{Col } 8 = \text{Col } 4 \times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} = \text{Col } 4 \times 0.0893$.

TABLE 17

Tractive Effort and Speed, Third Gear, Four-Speed Transmission with Commercially Available Power-Train Components

(Overall reduction = 8.56; power-train efficiency, excluding engine = 84 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	87.7	662	9.24	529.6	7.83
1000	103	19.6	116.9	742	16.45	593.6	10.52
1500	116.5	33.3	175.5	839	27.95	671.2	15.65
1700	119	38.5	198.5	856	32.35	684.8	17.72
2000	117	44.5	233.5	842	37.35	673.6	20.85
2500	111.5	52.6	292.0	803	44.20	642.4	26.10
3000	102	58.3	350.5	735	49.00	538.0	31.35
3500	91.4	60.8	409.0	658	51.10	526.4	36.50
4000	79	60.2	467.0	569	50.60	455.2	41.70

[a] $\text{Col } 4 = \frac{\text{Col } 1}{\text{reduction}} = \frac{\text{Col } 1}{8.56}$.

[b] Col 5 = Col 2 × reduction × efficiency = Col 2 × 8.56 × 0.84 = Col 2 × 7.2.

[c] Col 6 = Col 3 × efficiency = Col 3 × 0.84.

[d] $\text{Col } 7 = \text{Col } 5 \times \frac{12}{r} = \text{Col } 5 \times \frac{12}{15} = \text{Col } 5 \times 0.8$.

[e] $\text{Col } 8 = \text{Col } 4 \times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} = \text{Col } 4 \times 0.0893$.

TABLE 18

Tractive Effort and Speed, Fourth Gear, Four-Speed Transmission with Commercially Available Power-Train Components

(Overall reduction = 4.89:1; power-train efficiency, excluding engine = 86 percent; rolling radius r = 15 in.)

Engine rpm (1)	Net engine torque, ft-lb (2)	Net engine hp (3)	Wheel rpm (4)[a]	Wheel torque, ft-lb (5)[b]	Wheel hp (6)[c]	Tractive effort, lb (7)[d]	Vehicle speed, mph (8)[e]
750	92	11.0	153.5	387.0	9.46	309.60	13.70
1000	103	19.6	204.0	432.5	16 85	346.00	18.20
1500	116.5	33.3	306.0	489.0	28.65	381.20	27.30
1700	119	38.5	347.0	500.0	33.15	400.00	31.00
2000	117	44.5	408.0	491.0	38.30	392.80	36.50
2500	111.5	52.6	511.0	468.0	45.30	374.40	45.60
3000	102	58.3	613.0	428.0	50.20	342.40	45.75
3500	91.4	60.8	715.0	384.0	52.40	307.20	63.80
4000	779	60.2	817.5	332.0	51.80	265.60	73.00

[a] $\text{Col } 4 = \frac{\text{Col } 1}{\text{reduction}} = \frac{\text{Col } 1}{4.89}$.

[b] Col 5 = Col 2 × reduction × efficiency = Col 2 × 4.89 × 0.86 = Col 2 × 4.20.

[c] Col 6 = Col 3 × efficiency = Col 3 × 0.86.

[d] $\text{Col } 7 = \text{Col } 5 \times \frac{12}{r} = \text{Col } 5 \times \frac{12}{15} = \text{Col } 5 \times 0.8$.

[e] $\text{Col } 8 = \text{Col } 4 \times \frac{2 \times 15 \times \pi \times 60}{12 \times 5280} = \text{Col } 4 \times 0.0893$.

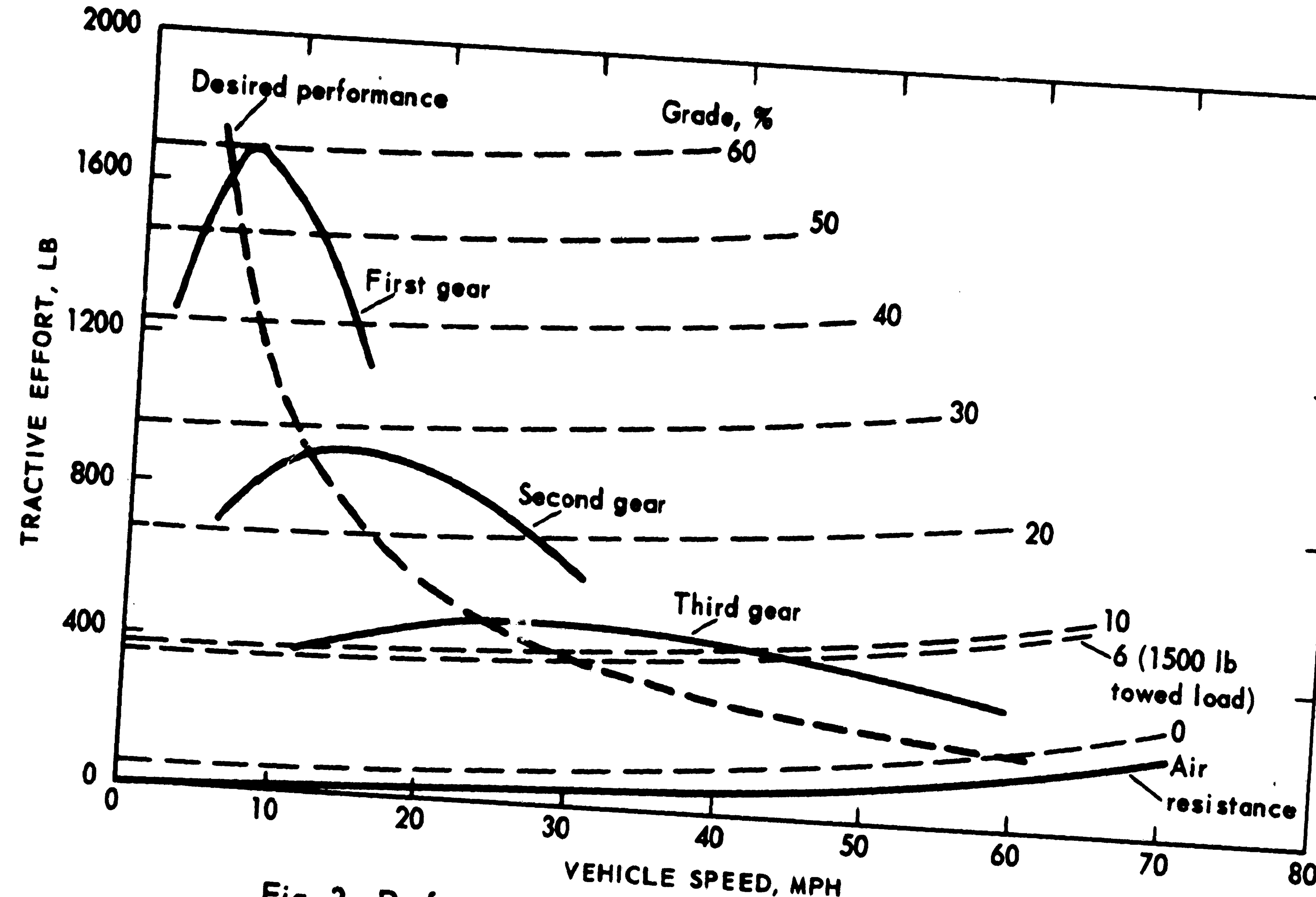

Fig. 2—Performance Curves, Three-Speed Transmission

QMR minimum requirement.

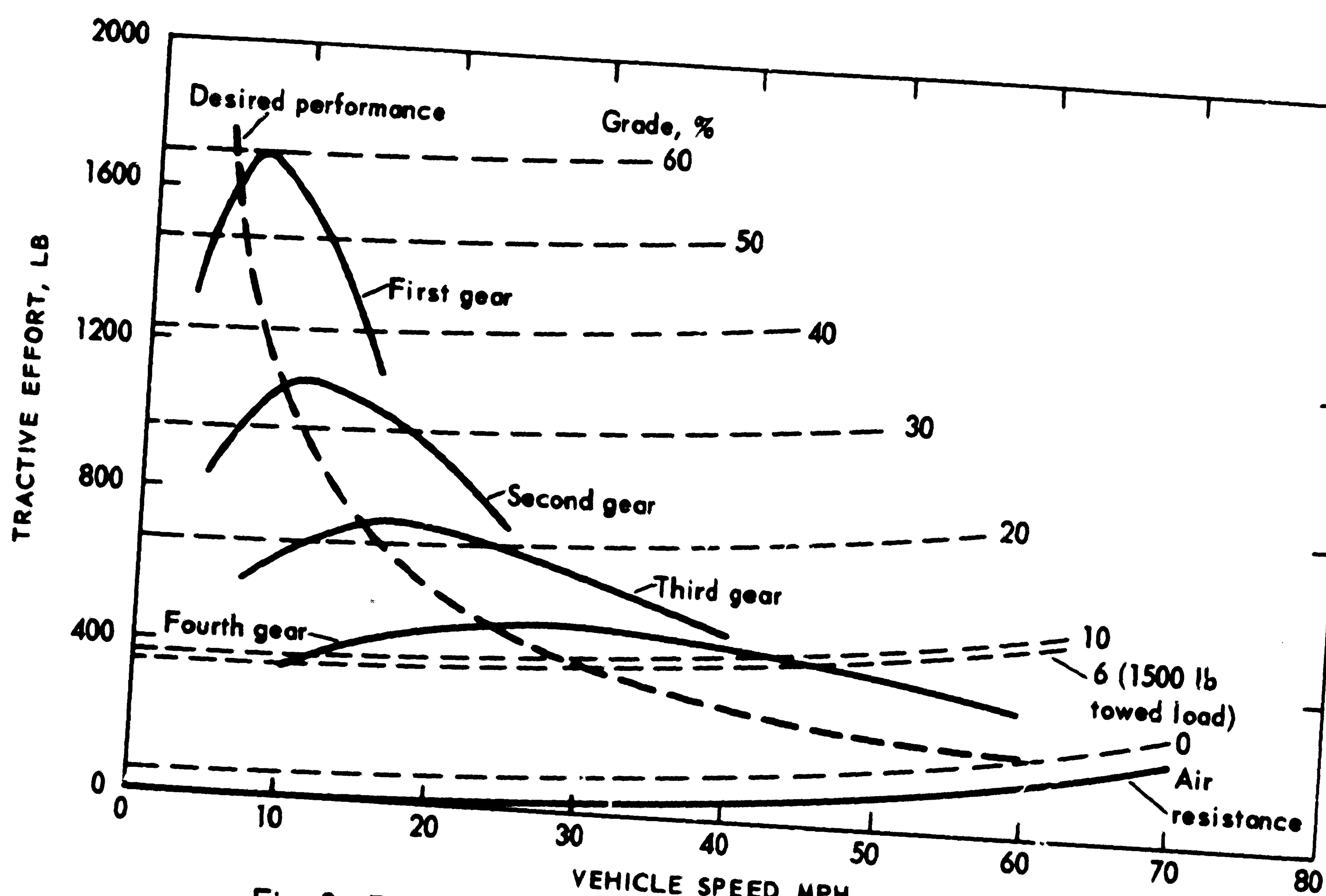

Fig. 3—Performance Curves, Four-Speed Transmission

QMR minimum requirement.

Engine Army Part No. 8754411, selected transmission ratios: first, 3.80:1; second, 2.44:1; third, 1.56:1; fourth, 1.00:1

Selected transfer-case ratio 1:1

Selected axle ratio 5.95:1

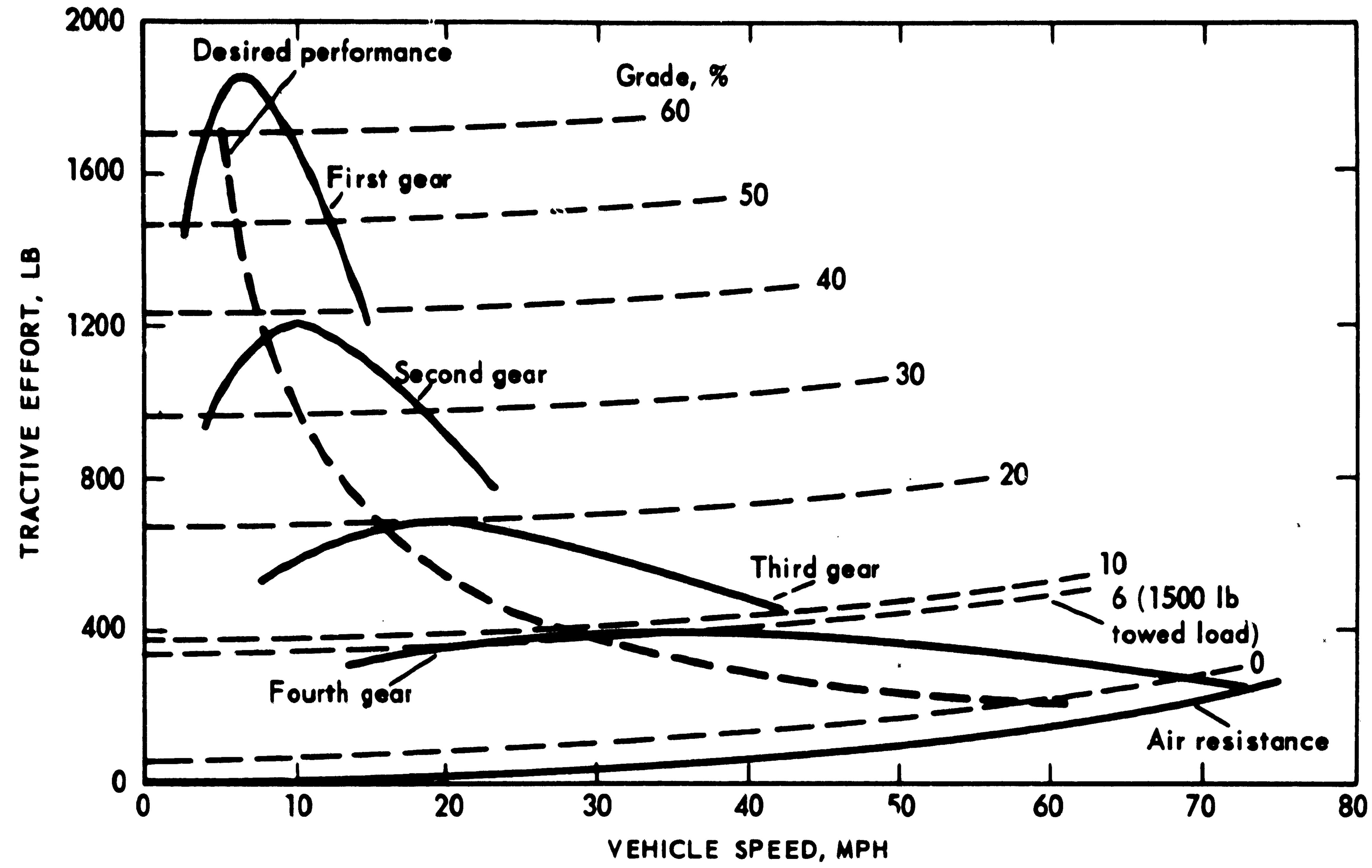

Fig. 4—Available Tractive Effort and Speed as Proposed with Commercial Power-Train Components

Engine Army Part No. 8754411 transmission–Borg-Warner SK4570C (T98A modified): first gear, 5.06:1; second gear, 3.217:1; third gear, 1.75:1; fourth gear, 1.00:1
B-W ·ransfer case ratio 1.00:1
Dana ⁄ xle Model 44 ratio 4.89:1
Tir rolling radius 15 in.

POWER-TRAIN-COMPONENT ANALYSIS AND SELECTION

Factors to be considered in this section are (a) engines: domestic vs foreign, gasoline vs diesel, gas turbine, liquid-cooled vs air-cooled, followed by engine type, power, speed, size, and cost; (b) transmission and transfer case: three-speed with single-speed transfer case, three-speed with two-speed transfer case, four-speed with single-speed transfer case; and (c) axle.

Performance characteristics of a power train that would meet the vehicle requirements were discussed in the preceding section. A final choice should be based on a combination of all components resulting in the best vehicle performance rather than the fitness of any one particular element within the power-train arrangement. There are a number of commercially available engines, transmissions, and rear axles to choose from, and even though the match with other transmission components is of great importance each component will have to be discussed individually to eliminate some that seem to have the capacity or meet the requirements, yet can be ruled out for various reasons.

Engines

Domestic vs Foreign. In the search for an engine as a prime mover for the proposed ¼-ton truck several foreign-made engines appear to be suited for the application. They are high-performance engines rated with much higher rpm than domestically made engines of the same type. These engines meet the power and speed requirements and their initial cost might be less than that of a domestic engine.

It is felt, however, that these factors are not necessarily the most important considerations in determining their compatibility. Consideration must be given to their reliability under severe off-highway conditions for which they were not designed. The maintenance problem might therefore become paramount. Difficulty of supplying or stocking parts and special tools for engines manufactured on the European continent would also create a problem.

It seems to be out of the question to purchase only the engines abroad. If this choice were made, then the complete power-train assembly should be purchased as a drop-in unit. Commercial experience indicates that it would be cheaper than to set up tooling to assemble the engine to the transmission.

Additional factors, not of a technical nature but possibly of equal importance, need to be realized before making the final selection between a foreign and a domestic engine. One would be the effect of the gold flow into foreign countries; the other the psychological effect of having a foreign-made engine or power plant installed in a US military vehicle. Finally the possible difficulties in maintaining supply in time of war, because of both ocean transport difficulties and possible change in the political situation in the producing country, would seem to be a preponderant consideration. Therefore it is felt that the selection of a domestic engine for the ¼-ton utility truck would be the better choice.

Gasoline vs Diesel. The choice between a diesel and a gasoline engine for military applications has often been decided in favor of the diesel engine. This is especially true when powering large heavy vehicles.

The diesel engine was considered as a replacement for the present M151 gasoline engine. A major advantage of a diesel engine over the present gasoline engine is that it would operate on lower grade fuels, such as SP4, diesel fuel, or kerosene. These fuels, having a much lower flash point than gasoline, would reduce fire and explosion hazards. Maintenance would be greatly reduced because the diesel engine does not require the electrical ignition system. This would eliminate the need for suppressing the ignition components to avoid radio interference.

It is a characteristic of the diesel engine to produce a higher torque than a gasoline engine of equal rated horsepower. Statistically the engine has a longer operating life expectancy with better power characteristics than the gasoline engine.

However, the application of a diesel engine in a small vehicle similar to the present ¼-ton utility truck has a number of disadvantages. Commercially available diesel engines weigh considerably more than gasoline engines developing the same horsepower. The physical dimensions of a diesel engine are also greater than those of the gasoline engine. This is particularly important in the ¼-ton utility truck, which is a small high-density vehicle; this factor may impose additional design problems. Although the operating cost of the

diesel engine is substantially lower than that of a gasoline engine the initial cost would be two to three times greater than that of a gasoline engine of comparable performance capability. In addition the engine with a compression-ignition system is quite difficult to start, particularly in cold weather, and would require a large battery capacity and associated generating equipment. Since the ¼-ton truck is required to operate under various conditions as a utility vehicle, and the maximum required horsepower is quite small compared to heavy-duty transport vehicles, the disadvantages of a diesel engine installation appear to outweigh the advantages.

Gas Turbine. In this study the gas turbine was considered as a replacement for the present reciprocating engine. A 70- or 80-hp gas-turbine engine would have some advantages over a reciprocating engine, since it has about one-fifth the number of parts. The turbine will run on gasoline, jet fuel, kerosene, diesel fuel, peanut oil, crankcase drainings, liquified petroleum gases, and other similar materials. Under normal conditions this type of engine has proved long-term reliability. For transmission and drive-train considerations, this engine has smooth flow torque to the drive shaft.

However, for the small-vehicle application, such as the ¼-ton utility truck, the gas-turbine engine has many disadvantages. The engine requires a large volume of air; the blades are quite vulnerable to airborne dust erosion, and if operating near salt water the salt air corrodes the blades and engine efficiency drops rapidly after 2 to 3 hr of operation.

The gas-turbine engine is essentially a one-speed high-rpm machine, and fuel consumption per horsepower increases quite rapidly at lower speeds. In addition the gas turbine must idle at 50 to 60 percent of its cruising speed to be self-sustaining.

The turbine engine is a high-precision machine requiring very close tolerances, excellent seals, and perfect balance of the rotating components. Maintenance of the machine requires highly trained and skilled personnel. Operating vehicles emit high-frequency sounds of high energy level, which could be hazardous to personnel. This characteristic is also tactically undesirable because of the increased possibility of detection by acoustic sensors.

Since the ¼-ton utility truck must operate under various adverse conditions at variable speeds, it appears that the gas-turbine engine would require considerably more maintenance than the reciprocating engine, the fuel consumption would be considerably greater, and the transmission and controls would be much heavier and more complicated to provide for a greater reduction of speed to the wheels. At the present state of the art the cost of the turbine would be many times greater than that of a standard military reciprocating engine. It is therefore concluded that the gas turbine should not be considered further for installation in the ¼-ton utility truck.

Air-Cooled vs Liquid-Cooled. The analysis of possible power sources has already revealed several requirements that limit the field of engines available for consideration.

Discussion of an air-cooled vs a liquid-cooled engine will develop the final characteristics on which a choice of engines can be made if matched with the proper transmissions.

The obvious prime advantage of an air-cooled engine is favorable if for only one reason—the elimination of the liquid cooling system and its related

parts, and with it the elimination of need for winterization. The water pump is no longer required, which effects a horsepower saving.

After having ruled out foreign manufacturers, the market of air-cooled engines in the required horsepower range is limited; the only one to be considered is the militarized 164 cu in., 6-cylinder, horizontally opposed Chevrolet Corvair engine, which delivers a maximum net 65 hp at 3600 rpm. The design of this engine incorporates a large belt-driven cooling fan located on top of the engine. Shrouding directs the airflow for proper cooling over and around the block, which makes accessibility for maintenance difficult. The horsepower saved by eliminating the water pump may be canceled out because of the more complicated belt-drive arrangement of the cooling fan. Owing to the horizontally opposed piston arrangement this engine measures about 13 in. wider than the one presently installed, which would complicate body and chassis design and make installation difficult.

The initial cost for this engine is several hundred dollars more than that of the Army Part No. 8754411. For these reasons the air-cooled engine is not recommended as a power source for the ¼-ton utility truck.

Summary. Through evaluation of the various types of engine available the following conclusions were reached.

Engine type. The best-suited engines for propulsion of the ¼-ton utility truck are liquid-cooled gasoline engines built by US manufacturers.

Power, speed, size. The vehicle's performance specifications as stated in the QMR determined the engine specifications set forth in the first part of this section. Table 19 is a list of engines (in alphabetical order) that will satisfactorily power the ¼-ton utility truck when matched with a suitable transmission.

TABLE 19

Engines Considered for the ¼-ton Utility Truck

Engine make	Cylinder	Displacement, cu in.	Hp at rpm		Compression ratio
Chevy II	4 I	153	90	4000	8.5
Falcon	6 I	144.3	85	4200	8.7
International Scout	4 I	151.8	93.4	4400	8.1
Army Part No. 8754411 engine	4 I	141.5	71	3900	7.5
Plymouth Valiant	6 I	137.5	101	4400	8.2
Willys Jeep	4 I	134.2	72	4000	.0

All these engines list the gross horsepower rating at a certain governed speed. It may be noted that after degrading the horsepower for accessory and efficiency losses, these engines will fall within the net requirements. Although some of these engines show more horsepower than required, their listing is justified from the standpoint of cost economy. These engines are presently produced commercially in high quantities. Their larger size, however, may create installation problems.

Cost. A cost study of these engines was made, the results of which are presented in Table 20. The cost of the presently installed M151 Army Part No. 8754411 engine was used as a basis of 100 percent of this comparison.

The engine analysis in this section of the report was primarily based on performance, size, and weight. The final design furnished by the manufacturer's engineering department would provide the detailed information required to qualify these engines. This study would reveal the necessary changes in the vehicle chassis to mount a specific engine. A new engine would require a new exhaust system, and the controls would have to be changed or modified. Also, commercial engines are not designed to Mil Specs and need to be changed to meet the Mil Spec requirements.

The cost of modifying commercially available engines or engine accessories was not included in this engine cost comparison.

TABLE 20

Relative Cost of Engines Considered

Engine make	Cost of ordnance, %	Cost increase above ordnance, %	Cost saving, %
Chevy II	87.5		12.5
Ford Falcon	108	8	
Plymouth Valiant	117.4	17.4	
Jeep	100		
International Scout	115.6	15.6	
Army Part No. 8754411	100		

Transmission and Transfer Case

The present power arrangement of the M151 offers a design desirable for many applications in the automotive field. This installation with engine, clutch housing, transmission, and transfer case in one compact unit, without drivelines, makes it a rigid dependable assembly.

In the search for a design to improve the vehicle's performance or offer equal performance for less cost, various combinations of engines, transmissions, and transfer cases are discussed in the following paragraphs.

Three-Speed with Single-Speed Transfer Case. Three-speed transmissions can be found in many of today's trucks and are considered reliable powertrain components by the automotive industry. Most of these vehicles are designed for secondary road and occasional off-highway conditions, but not in the extreme environment specified in the QMR to which the ¼-ton truck might be subjected. The effect of a three-speed transmission on an engine was briefly discussed in a preceding subsection. Many engines are not designed to operate at constant full load. An engine with different characteristics would be required to be matched with a three-speed transmission for the power train of the ¼-ton utility truck. Even then the three-speed transmission with a single-speed transfer case would not completely cover the various speed and power ranges required to furnish satisfactory performance.

Three-Speed with Two-Speed Transfer Case. A three-speed transmission in combination with a two-speed transfer case is often used in power trains for small- and medium-sized trucks with off-highway requirements. The Chrysler Corporation uses this arrangement in most of its six-cylinder-powered vehicles and matches the Model 903 transmission with a Spicer Series 18 or 20

two-speed transfer case. This design uses helical gears for quieter operation and is synchronized between second and third gear. The standard version provides a remote control, but a manual shift and cover are available and ready for mounting.

The M38A1 jeep utilizes the same power-train arrangement. The three-speed-transmission–two-range-geared-transfer-case arrangement is composed of commercial assemblies that are tooled for high production. It is of rugged construction and if installed in the ¼-ton truck would perform satisfactorily within the requirements. It has only one synchronized downshift, however, and the vehicle must be slowed to almost a stop to shift the transmission into low speed. The same applies for the low range in the transfer case. In order to shift into low range, the four-wheel drive must first be engaged. The transfer box is noisy, and two levers are required to operate the low range and four-wheel drive. This makes a total of three levers to be handled by the driver, whereas the arrangement of a four-speed transmission would require only two levers—one for gear shift, the other for four-wheel-drive engagement.

Four-Speed with Single-Speed Transfer Case. The four-speed transmission in connection with a single-range geared transfer case, as presently installed in the M151, has proved satisfactory under all driving conditions.

From the standpoint of handling ability this unit appears to have better features than a three-speed two-gear transfer-box lever arrangement. It is not commercially available, however, and its low-volume production tooling with close machining tolerances and fine finishes makes this assembly more expensive.

The Borg-Warner Gear Division has developed an assembly to replace the present M151 and M38 transmission and transfer case. It is the present T98A B-W four-speed SK4570C truck transmission in conjunction with a newly developed single-range transfer case. The transmission portion is a high-volume production item used by several well-known truck manufacturers. The three top gears are synchronized, giving the driver greater flexibility in handling the vehicle under varying conditions. The high-production quantity makes this design attractive from the standpoint of cost. It is capable of handling almost twice the torque developed by the QMR engine. This feature adds to the weight of the unit, which is much greater than the presently installed M151 transmission, but reliability will be assured.

Other commercially available transmissions within the required range are widely used for passenger cars. Even though their greater production tooling makes them less expensive the necessity of a transfer-box installation to provide for a four-wheel drive would more than offset the initial gain in cost. Furthermore the passenger-car transmissions are of less durable construction. They are not therefore recommended for installation in the ¼-ton utility truck.

Summary. Passenger-car transmissions have been ruled out for installation in the ¼-ton truck, and a truck transmission is the choice for this power-train arrangement.

The match of a three-speed transmission with a single-speed transfer box was also disregarded as a power-train component for this application.

This limits the choice of a transmission–transfer-box combination to the three-speed transmission–two-speed transfer box or the four-speed trans-

mission–single-speed transfer box. Either of these is acceptable if power and speed as well as gear reduction meet the vehicle's specification requirements. The final selection was determined by evaluation of performance, reliability, weight, and cost.

Even though the three-speed-transmission–two-speed-transfer-box arrangement will satisfy the vehicle's requirements in transmitting speed and torque, it increases difficulty of operation. The four-speed-transmission–single-speed-transfer-box design is the more refined of the two. The four forward speeds synchronized in the top three gears allow operation of the vehicle with less demand on the operator. It offers a cleaner design with only two control levers protruding into the driver's compartment.

Based on actual field reports, the reliability of these two designs was considered equal. This statement, however, pertains only to the comparison of the present M151 and M38A1 transmissions, since information from other transmission manufacturers regarding reliability of their products was not available at this time.

In Table 21 several transmissions and transfer-box assemblies were compared in weight and cost with the corresponding components now installed in the M151 vehicle.

In col 7 the cost of the transmission was compared to its torque rating. These figures give the cost for 1 ft-lb of torque, and the lowest value, therefore, indicates the best choice.

Column 8 expresses the relation of transmission weight to transmission torque rating. This kind of comparison is commonly used when discussing engines where engine weight is related to engine horsepower. It tells in this case how much 1 ft-lb of torque weighs. Again a minimum is desired for the best selection. This is not always true, since an aluminum transmission case or an inferior transmission design where weight saving was stressed could result in a lower ratio value. In this case, however, neither of these possibilities was considered.

Column 9 is a combination of cols 7 and 8. It shows the ratio of cost of 1 ft-lb of torque to the weight-to-torque ratio of the transmission. Here again the lowest value is generally preferable.

Table 22 lists the transmissions from Table 21 in order of first, second, third choice, etc., starting with the lowest value found in col 9.

According to Table 22 the first choice in the transmission–transfer-box selection is the Borg-Warner T98A four-speed transmission in connection with a single-speed transfer box. This combination bears the Borg-Warner number SK4570C.

It has the highest torque rating of the units listed above, and since transmission torque is almost directly proportional to transmission weight, as can be noted in the weight-per-torque-ratio column, this unit is therefore also the heaviest. From the standpoint of durability and performance this unit will perform quieter and better and require less service and maintenance, which might be more than worth the weight differential. From the cost standpoint this unit is priced slightly higher than the transmission listed as second choice, yet costs only a little over half as much as the one now installed in the M151. Therefore it is felt that this transmission and transfer-box assembly would offer the most in performance reliability and cost for this application.

TABLE 21

Characteristics of Various Transmission–Transfer-Box Assemblies

Transmission (1)	Transmission gear ratios (2)	Transfer case (3)	Estimated weight, lb (4)	Estimated cost, dollars (5)	Torque rating, ft-lb (6)	Cost/torque ratio (7)	Weight/torque ratio (8)	Cost/weight ratio (9)
Army Part No. 7536199, present M151	4	Integral with transmission 1-speed	115	230	120	1.92	0.96	2
Borg-Warner T90C, present M38A1	3	Separate Dana 18 2-speed	125	115	130	0.885	0.963	0.92
Jeep, commercial	3	2-speed	125	155	120	1.29	1.04	1.24
International Harvester Scout	3	2-speed	110	148	135	1.1	0.815	1.35
Borg-Warner SK4570C T98A	4	1-speed	200	125	220	0.568	0.91	0.625
Ford truck 303, fully synchronized	3	2-speed	165	205	180	1.14	0.916	1.245

The second choice is the Borg-Warner T90C three-speed transmission in conjunction with the Dana Model 18 transfer case. This combination meets the requirements very well.

The torque capacity slightly exceeds the maximum engine output torque, and yet the transmission weight is kept low. The initial cost is lower than that of any transmission listed above.

TABLE 22

Transmission–Transfer-Box Selection

Transmission	Estimated weight, lb	Estimated cost, dollars	Torque rating	Cost/torque	Weight/torque	Cost/weight
Borg-Warner SK4570C	200	125	220	0.568	0.91	0.625
Borg-Warner T90C M38A1	125	115	130	0.885	0.963	0.92
Jeep, commercial	125	155	120	1.29	1.04	1.24
Ford truck 303	165	205	180	1.14	0.916	1.245
Scout	110	148	135	1.1	0.815	1.35
Army Part No. 7536199, present M151	115	230	120	1.92	0.96	2

This assembly, now installed in the M38A1, would make the ideal power-train component if the two-speed transfer case were synchronized so that it could be shifted while the vehicle was in motion. As it is now, this unit is reliable, composed of assemblies easily maintained and serviced, but not as easy to operate as a four-speed transmission. It would make a cheap, austere power-train component, but it is considered only as second choice.

Rear Axle and Differential

The present M151 design features a differential cross-drive arrangement for rear and front wheels. The front-wh el drive can be either disengaged or engaged for four-wheel-drive operation. Front and rear differentials are identical, incorporating a 4.86 to 1 reduction.

Power is transmitted from the transmission transfer case by means of drive shafts into the differentials and out to the wheels.

A differential lockup was not incorporated in this design because of the requirement for this axle to be interchangeable with a ¾-ton 6 by 6 truck axle. A lack of space made the provisions for differential lock-up impossible.

The design of the present M151 differential cross drive has proved to be of satisfactory lightweight construction that, from the standpoint of performance, probably cannot be improved on without involving a major redesign.

The individual coil-spring suspension in conjunction with the differential cross drive assures good roadability on highways and secondary roads. Field reports, however, indicate that this suspension system leaves much to be desired during cross-country operation. It does not give the riding stability and "feel of the vehicle" that a rigid differential axle with leaf-spring suspension will provide.

Consideration of a different type of axle and suspension system for the ¼-ton truck in order to achieve greater reliability and ruggedness will consequently change axle weight, performance, and cost.

The two best-known axle and suspension designs are the differential cross drive with coil-spring suspension, as installed now in the M151, and the differential axle with leaf-spring suspension. The first is exclusively used in today's passenger cars and the latter finds application in various other types of automobiles, mainly in trucks and off-highway vehicles and therefore remains the only alternative choice for installation in the ¼-ton truck.

The M38A1 incorporates this design. It is heavier than the M151 construction but is believed more rugged and less vulnerable than the differential cross drive with exposed drive shafts leading to the wheels.

Several truck axles commercially available could be adapted with minor modifications. Selection of identical components for front and rear axle would simplify maintenance and spare-parts requirements. This, of course, pertains only to the differential portion of the assembly since the different attachment of the front wheels for steering purposes makes complete interchangeability impossible.

Some truck-axle manufacturers feature a limited-slip differential as an optional design that can be added for very little cost and weight increase.

This differential is self-controlled and capable of adapting its function to any ground or surface condition, thereby adding to the vehicle's cross-country riding stability and eliminating steering correction when slipping wheels.

If a truck-axle design should be preferred over the present M151 design it is suggested that the limited-slip differential be incorporated as a standard part of the assembly.

It is believed that during normal highway operation a vehicle with rated payload and coil-spring suspension does not offer much greater riding comfort than a vehicle with a leaf-spring suspension under the same conditions. On secondary roads, however, the coil-spring suspension proves superior, but during cross-country operation the leaf-spring suspension will perform more favorably. According to the QMR the ¼-ton truck is expected to operate under normal conditions 30 percent on highways, 40 percent on secondary roads, and 30 percent on cross country. Table 23 shows the performance of the suspensions under normal driving conditions.

Under battle conditions the QMR estimates that the vehicle idles 40 percent, operates cross-country 40 percent, and operates on secondary roads 20 percent. Table 24 shows the suspension performances under battlefield conditions.

Tables 23 and 24 indicate that under normal conditions the differential cross drive with coil-spring suspension proves to be 10 percent better than the differential axle with leaf-spring design, but the leaf-spring design under battlefield conditions shows 20 percent better application, giving it a total advantage of 10 percent over the coil-spring arrangement.

Although this comparison may not disclose the final choice of axle design, it indicates that from the standpoint of performance, especially when considering the superior cross-country qualification, the differential axle with leaf-spring suspension may be better suited for installation.

The last evaluation of these two designs is a trade-off between weight and cost.

A weight comparison of several differential truck axles that would be suited for installation in the $\frac{1}{4}$-ton truck revealed an average of 80 percent weight increase over the present M151 design. Studies have proved, however, that this additional weight would not affect the capabilities of the vehicle to the extent of its falling short of the requirements listed in the QMR.

From the standpoint of cost the present M151 axle design would definitely be more expensive; approximately 50 percent cost saving could be achieved by installing a limited-slip differential truck axle with leaf-spring suspension.

TABLE 23

Suspension Performances under Normal Driving Conditions

Driving condition	Coil-spring suspension	Leaf-spring suspension
Highway, %	30, good	30, good
Secondary roads, %	40, good	40, not as good
Cross-country, %	30, not as good	30, good
Total, %	70, good	60, good

TABLE 24

Suspension Performances under Battlefield Conditions

Driving condition	Coil-spring suspension	Leaf-spring suspension
Idle, %	40	40
Secondary road, %	20, good	20, not as good
Cross-country, %	40, not as good	40, good
Total	60, good	80, good

After evaluating various available truck axles and comparing their compatibility with the present M151 differential cross-drive design it is believed that a truck axle with leaf-spring suspension would be the better choice for this type of vehicle. The best suited axles for this application are the Dana Models 44 front and 44-3 rear axles, which are proposed to take the place of the present M151 axle installation.

ELECTRICAL SYSTEM

Introduction

A substantial cost difference exists between the commercial and military electrical systems. This is due to the more stringent specification requirements applied to the military system. The military electrical system meets the requirements of the Mil Specs with respect to shock, vibration. waterproofing, fungus resistance, the ability to withstand ambient temperature changes

and other environmental conditions, and the suppression of radio interference. In order to meet these specifications, production must necessarily be limited, since these components would not normally be used in a commercial application. This substantially increases the cost of the system. The commercial components, on the other hand, are in high production and are available at minimum cost. Competition and the ability to automate production enables the manufacturer to keep the prices at a minimum, and more than one source is assured.

A good approach to reducing the cost of the electrical system may be to utilize as many commercial components as possible with slight modifications where necessary. Some of the present commercial components may now meet the military requirements. The electrical system will be divided into subsystems and will be analyzed to determine the effectiveness of this approach.

Comparison of 12- and 24-v Systems

The first consideration given the vehicle's electrical system was to determine voltage and type. The standard military electrical system for most wheeled and tracked vehicles is the 24-v dc single-wire system with a negative ground return. Although many of the commercial components are designed for a 12-v dc system the 24-v dc system has these advantages:

(a) Standard military electrical components are presently produced in limited quantities.

(b) The higher voltage 24-v dc system contributes greatly to cold-weather starting as compared to the 6- or 12-v system.

(c) The size and weight of the electrical conductors is reduced considerably.

(d) The size and weight of the static and dynamic power source is reduced.

(e) Compatibility with other military vehicles would be assured with the 24-v dc system.

(f) It is possible to slave a disabled vehicle with other military vehicles as an aid in starting with no detrimental effect on the electrical system of either.

To demonstrate the effectiveness and reliability of the 24-v dc system for engine starting, a study, the results of which are given below, was made of the number of starts that could be made under certain conditions. This study points out an advantage of using the 24-v dc system in which the number of engine starts increases 226 percent over the 12-v dc system. This fact becomes more important when considering cold-weather starting, when battery capacity is reduced drastically.

For example, a starter designed for a 12-v dc system will have an efficiency of approximately 52 percent compared to efficiency of approximately 60 percent for a 24-v dc system. From this it follows that the current requirements would be more than double in changing from a 24-v dc system to a 12-v dc system. For example a 12-v dc starter will draw 380 amp for an assumed period of 10 sec for each start. The military battery 2HN, as used in the ¼-ton truck, has a 45 amp-hr capacity at a temperature of 80°F. The ampere-hours required per engine start is

$$380 \times 10/3600 = 1.05 \text{ amp-hr}$$

Thus the number of starts available, neglecting the system loads, generating capacity, and other conditions, is equal to

$$45/1.05 = 42.8$$

starts for the 12-v system.

A 24-v dc system also has a 45 amp-hr capacity incorporating two 2HN batteries. The 24-v dc starter will draw 167 amp for an assumed period of 10 sec for each start. The amp-hr required for each engine start is

$$167 \times 10/3600 = 0.464 \text{ amp-hr}$$

Thus the number of engine starts available, neglecting system loads, generating capacity, and other conditions, is equal to

$$45/0.464 = 97$$

starts for the 24-v system.

The percentage increase in the number of engine starts is equal to

$$97 \times 100/42.8 = 226\%$$

Thus it follows that the reliability of the entire vehicle is increased by the use of the 24-v dc system.

Static Power Source

The static power source for the ¼-ton truck consists of two 12-v batteries connected in series to produce a total of 24 v. A study has been made of the commercial batteries now available, but the results of this study indicate that the military battery conforming to the MS-35000 series presently specified on the M151 should be retained because (a) the military battery is presently in high production and is being produced at a reasonable cost; (b) the life of the military battery is substantially higher than that of its commercial counterpart; (c) the military battery is designed to meet the thermal shock encountered during use of the cold-weather starting aids, and even if these requirements were slightly reduced the overall cost would not be reduced; (d) the military battery is in normal supply channels now and interchangeability is ensured; (e) the standby and starting capabilities of the vehicle are increased substantially; and (f) the cost of a single 12-v battery would be approximately half that of the 24-v system, but the reliability of the vehicle would be reduced substantially.

Instrumentation

The present M151 vehicle is instrumented with an oil-pressure gage, fuel-level gage, temperature gage, and battery-generator gage. These military gages are waterproof, Ordnance-approved, and fairly low-cost items. They will meet the specification MIL-I-10986A and are designed for indirect lighting,

which will meet the blackout operating conditions. The respective activating units for these gages, with the exception of the battery-generator-condition gage, which does not require one, are fairly low-cost units, but they require frequent replacement in the field with loss of instrumentation during the repair period.

A study was made to determine methods of increasing reliability at minimum cost. Two methods of improving reliability are discussed here. Each represents an increase in initial cost over the present system.

One method of improving reliability is to provide gages that are more accurate, rugged, easily readable, and provided with substantially more reliable activating units. There are commercially available instruments presently specified on several military vehicles. The scale is expanded on these gages to 300 °F, compared to 60 deg on the present Ordnance gages. The initial cost is about six times that of the currently specified gages.

A method of improving reliability at a lower initial cost is to provide a dual arrangement of gages and a warning light. The driver's awareness of malfunctions could be substantially increased by use of a single warning light that would flash intermittently until the malfunction was corrected. All or any combination of the engine malfunctions could be monitored, such as low oil pressure, high water temperature, low fuel level, and generator "off."

To arrive at the lowest cost for instrumentation, individual warning lights could be substituted for all gages except the fuel-level gage. This method is similar to that practiced in the automotive trade. It is felt, however, that this instrumentation would not be suitable for use in military vehicles since informative readings are not presented.

After considering all the factors involved, including the logistics of supply, it is recommended that the present military instrumentation system as used on the M151 vehicle be retained. A study of several vehicles instrumented with improved gages should be conducted at a later date.

Cabling

The cabling specified for the M151 conforms to specification MIL-C-13486. This cable is widely used in military equipment and is compatible with the quick-disconnect connectors commonly in use at this time. Although data are lacking, this cable has been found to deteriorate in storage even though it is made of Neoprene. The state of the art in wire insulation has improved to the point where a study should be made with a view to selecting a cable with improved shelf life, less weight and size, and a higher dielectric constant. The present cable is designed to be operated at 30 v dc. Thus the dielectric strength of the wire insulation is less than that required for a cable operating at 110 v. But the normal aging of the existing cable reduces the dielectric strength of the insulation to where arcing that would cause a cable failure may occur. A cable rated at a higher voltage but operating at 30 v dc would continue to operate for a longer period of time, even though the dielectric strength decreased in storage or use.

Commercial cabling is available, but because of the incompatibility of the existing connectors a waterproof assembly could not be made economically. Therefore it is recommended that the existing cabling be retained.

Fuel Pump

The M151 incorporates an electrically driven fuel pump and filter assembly that is mounted in the fuel cell. This method involves increased costs and complicated servicing.

An externally mounted electrically driven fuel pump and an in-line fuel filter that would improve maintainability and reduce costs were considered. However, to arrive at the maximum cost savings it is recommended that the electrically driven fuel pump and associated oil-pressure switch be ertirely eliminated in favor of an engine-driven diaphragm pump. If the electrically driven fuel pump were eliminated then the fuel tank could also be simplified with a reduction in costs. It is realized that the possibility of vapor lock could increase with the elimination of the electric fuel pump, but certain steps can be taken to help alleviate this possibility: (a) route fuel supply lines away from heat-producing components such as the exhaust manifold; or (b) where the fuel supply line may be in proximity to heat-producing components, appropriate shielding such as baffle plates or insulation on the fuel supply line can be used.

A low-cost in-line fuel filter that can be easily replaced is recommended to increase the reliability of the fuel system and to guard against the entrance of water and contaminants into the fuel system.

Ignition System

An internal-combustion engine requires an ignition system to fire the explosive gas mixture at the proper time. For a military vehicle, this system should be resistant to shock, vibration, fungus, and moisture, and should meet the radio-noise-interference specification and the requirements of ambient-temperature conditions.

A military ignition system consists of an igniter that includes the distributor and coil enclosed in a waterproof case, shielded and waterproof ignition leads, and special sparkplugs. The igniter and associated equipment are low-production items and therefore costly.

The commercial ignition system consists of a distributor, ignition coil, high-tension ignition leads, and conventional sparkplugs. These components are high-production items and are therefore less costly. Also more than one source is usually assured. If the military ignition-system specifications were relaxed to allow splashproofing rather than waterproofing, and the radio-noise-interference specification were relaxed slightly, it is entirely feasible to use a commercial ignition system modified to 24 v with radio interference suppression. A radio-interference-suppression kit is available for use on commercial ignition systems to reduce the radio-noise-interference level to within 90 percent of the Mil Spec. The advantages of the commercial system are (a) minimum cost, (b) excellent maintainability, (c) multiple source procurement, (d) life equivalent to the Mil Spec, and (e) standard test equipment and tools. The disadvantages are (a) the system is not waterproof and would not be suitable for a water-submerged engine, and (b) the rigid radio interference specification MIL-S-10379A could not be met 100 percent, but the radio interference specification MIL-I-11683 can be met.

A cost comparison reveals that the initial cost of the commercial shielded system is approximately $2.00 less than that of the military system. From a

service and replacement standpoint the commercial shielded system enjoys an ever greater cost advantage. However, for purposes of this study it is recommended that the military ignition system be retained.

Lighting System

The lighting system is composed of three systems: service lighting, blackout lighting, and instrument lighting. The service lighting incorporates two service headlights, two service taillights (including the rear turn lights), and two front turn lights. The military service headlights are completely waterproof and shock-mounted to reduce premature failure of the filaments in the sealed-beam units. The commercial units are designed for 12 v dc and are neither shock-mounted nor waterproofed at the electrical connector. It is recommended that the shock-mounted units be retained because of the fragility of the 24-v dc filaments in the sealed-beam units. Relaxing the waterproof requirements to splashproof would still provide a functional unit, but the cost savings would not be appreciable since the 24-v dc units are not extensively used commercially.

The service taillights are designed to include the blackout taillights; therefore a commercial counterpart is not available to analyze. The military taillight is waterproof and resistant to fungus and corrosion.

The blackout lighting includes the blackout driving lamp, two front blackout marker clearance lamps, one blackout stop lamp, and the rear blackout marker lamps incorporated in the service tail lamps. Since none of these lights has a commercial counterpart, a direct comparison of costs is not available. The military blackout lighting units are waterproof and resistant to fungus and corrosion. Several sources are presently available, ensuring the lowest cost for the lamps as they are now designed. A more extensive cost and engineering analysis should be made to determine if a redesign would reduce costs substantially. At present these units are used on most military vehicles and are in normal supply channels.

Instrument Lighting

The instruments are illuminated indirectly by two lamps that are waterproof and resistant to fungus and corrosion. These panel lamps are designed to meet the requirements of blackout lighting and are fairly low-cost items. A direct commercial lamp that would interchange with these units is not available and a redesign would be required to adapt the low-cost commercial lamp assemblies. It is recommended that the existing panel lamps be retained.

Power Analysis

The power analysis as shown in Table 25 is a close estimate of the electrical power requirements for a ¼-ton truck. In compiling this study certain operating conditions were taken into consideration as follows: (a) service lights were on, (b) engine was running, (c) blackout lighting was off, (d) battery was recharging at a rate of 15 amp, (e) turn signals were on, and (f) a GRC-19 communication radio set was on standby and transmitting with a ratio of 5 receptions to 1 transmission respectively.

With 15 amp allocated to battery recharging, the continuous demand load is 46.53 amp and the intermittent demand load is 169.30 amp. The largest demand load is that required to operate the communication equipment. Many types of radio equipment are available for use on the $\frac{1}{4}$-ton truck, and individual sets or combinations of sets are used as required. The power requirements vary widely between different radio sets, and to arrive at a practical value for use in the power analysis a study was made of the radio sets scheduled for use on the $\frac{1}{4}$-ton truck.

TABLE 25

Electrical Power Analysis

Description	Current requirement per unit, amp	Quantity	Total current required for land operation, amp	
			Continuous service	Intermittent service
Lights				
Head, service	2.84/2.14	2	5.72	
Head, blackout	0.59	1	na[a]	
Turn, service	0.92	2	1.84	
Marker	0.19	2	na	
Stop, service	1.15	2		2.30
Tail, service	0.23	2	0.46	
Tail, blackout	0.19	2	na	
Panel	0.17	2	0.34	
Indicators				
Pressure	0.01	1	0.01	
Temperature	0.01	1	0.01	
Fuel	0.01	1	0.01	
Battery-generator	0.01	1	0.01	
Hi-beam	0.13	1	0.13	
Pump, fuel	0.25	1	0.25	
Starter	167	1		167
Coil, ignition	4.00	1	4.00	
Relay, turn	0.25	1	0.25	
Relay, turn	0.25	1	0.25	
Relay, turn	0.25	1	0.25	
Radio, ANGRC-19	45.00 Transmitting		18.00[b]	
Battery Recharging			15.00	
Totals			46.53	169.30

[a]Not applicable.
[b]Average current requirement based on receive-transmit ratio of 5 to 1.

The complete list of all the single radio installations is shown in Table 26, and the average current requirements are plotted in Fig. 5, using a number code to identify the sets. Table 25 shows the normal system load of 13.53 amp, which does not include the battery recharging rate and the communication-equipment power requirements. Since the existing generating capacity is 25 amp, the maximum battery recharging rate available during night operation is 25 - 13.53 = 11.47 amp.

A desirable battery recharging rate as shown in the power analysis (Table 25) is 15 amp, which would recharge the batteries from 50 percent capacity to 100 percent capacity as follows:

> 50 percent capacity of 45 amp-hr battery is 22.50 amp-hr
> Recharging rate is 15 amp-hr
> Total vehicle running time (above idle) to recharge batteries is 22.50/15 = 1.5 hr

TABLE 26

Single Radio Installation and Power Requirements for ¼-ton Truck[a]

Code	Radio set	Approximate power required, amp	Code	Radio set	Approximate power required, amp
1	VSC-1	85 TWX	22	VRC-17	4
2	VRC-46	85 TWX	23	VRC-18	4
3	VSC-2	52 TWX	24	VRC-44	4
4	VRC-55	34 Retransmission	25	VRC-48	4
5	VRC-38	34 Retransmission	26	VRC-12	3.3
6	GRC-19	18	27	VRC-47	3.3
7	VRC-35	17 Retransmission	28	VRC-19	3
8	VRC-54	17 Retransmission	29	VRC-34	3
9	GRC-106	13	30	GRC-87	3
10	VRC-24	11	31	VRC-6	3
11	VRC-49	10 Retransmission	32	PRC-10	3
12	VRQ-1	8	33	PRC-9	3
13	VRQ-2	8 Retransmission	34	PRC-8	3
14	VRQ-3	8 Retransmission	35	VRC-10	3
15	GRC-3	6	36	VRC-9	3
16	GRC-5	6	37	VRC-8	3
17	GRC-7	6	38	VRC-7	2.5 Retransmission
18	GRC-4	5	39	VRC-43	2.5
19	GRC-6	5	40	GRR-5	2
20	GRC-8	5	41	VRC-53	0.7
21	VRC-16	4	42	GRC-125	0.7

[a]Receive-transmit ratio 5 to 1 except as noted, i.e., TWX service or retransmission.

By reducing the recharging rate to 11.47 amp the total vehicle running time (above idle) to recharge batteries is 22.50/11.47 = 1.96 hr. Considering overall vehicle usage, the recharging time should be within the 2-hr range; thus the 11.47-amp battery recharging current is considered a minimum requirement.

By referring to the curve in Fig. 5 it can be determined that with the use of any radio communication equipment the battery recharging current is reduced below the minimum recommended amount.

In Fig. 6 the power requirements of the winterization kit were included. Not only is the battery recharging rate reduced below the minimum recommended amount, but with the addition of any radio equipment the total generating capacity is consumed, neglecting the battery recharging rate. The recommended generating capacity of 60 amp is also shown in this figure, and it can be seen that the power requirements of all but three of the current radio sets proposed

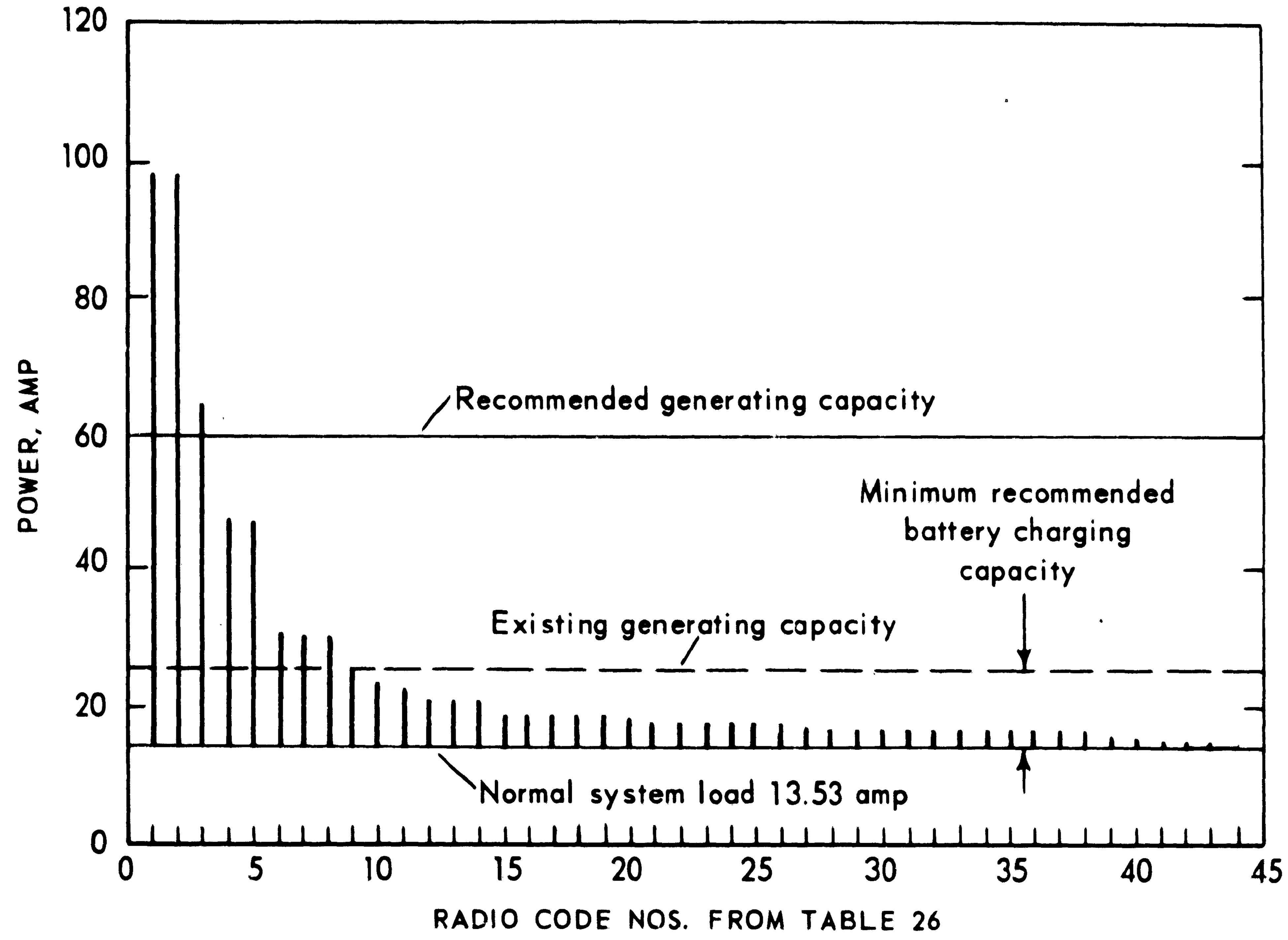

Fig. 5—Power-Demand Chart of Various Single Radio Installations

Normal nighttime operation.

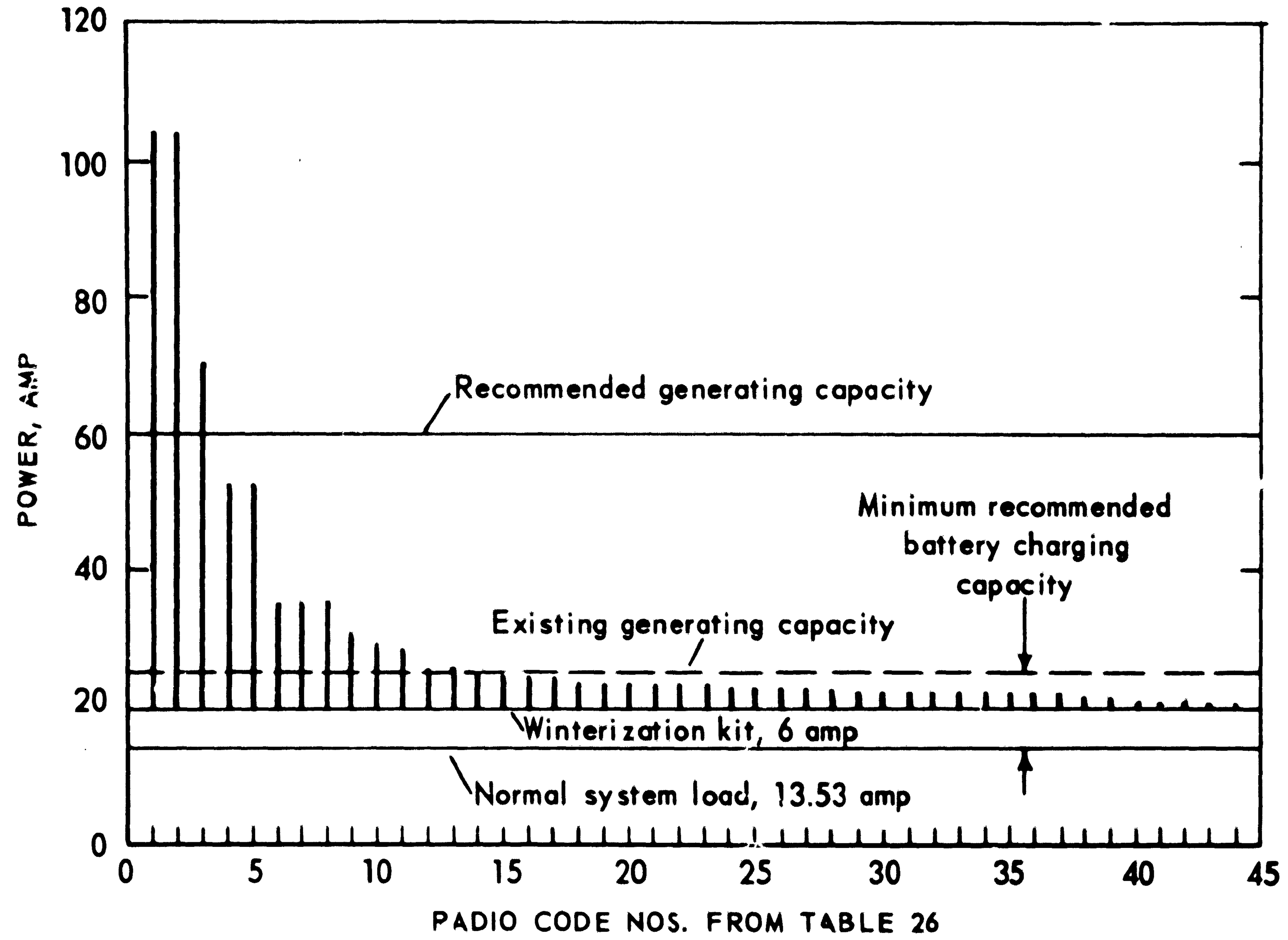

Fig. 6—Power-Demand Chart for Various Single Radio Installations plus Winterization Kit

Normal nighttime operation.

for use on $\frac{1}{4}$-ton trucks are satisfied. These will be discussed later. The use of the 60-amp generating source assures that the battery recharging requirements and future capacity for the use of kits will be met.

The complete list of all the multiple radio installations is shown in Table 27, and the average current requirements are plotted in Figs. 7 and 8, using a number code to identify the sets. The existing generating capacity without the use of the 100-amp alternator kit is not sufficient to meet all power requirements. However, the 60-amp proposed alternator does have the capacity to meet all the requirements including the winterization kit as shown in Fig. 8.

The radio-teletype sets ANVSC-1, ANVRC-29, and GRC-46 all require 85 amp, which is the maximum power consumption of all the sets considered, and the duty cycle could reach 100 percent. However, since the density of usage is very low, these sets should be treated as exceptions; when use of these sets is dictated, a portable power supply in addition to the vehicle's own generating system should be used. In the event a portable power supply is not available, additional power could be obtained by slaving one vehicle to another so that the generating systems of both vehicles could be utilized.

The next set considered was the radio-teletype ANVSCS-2, which also has low-density use. The power requirement is 52 amp, and this duty cycle may also reach 100 percent. A 60-amp alternator on the vehicle would supply sufficient power to operate the set but with little battery-charging capability.

The last set to be considered that requires any substantial amount of power is the ANGRC-19. With a ratio of 5 receptions to 1 transmission, the power requirement averages 18 amp. A 60-amp alternator is more than sufficient to supply the requirements for operation of the radio equipment and other system loads.

All the other radio sets used in the $\frac{1}{4}$-ton truck require less power than those previously considered.

Generating System

The generating capacity of an electrical system is determined by certain criteria that include the normal demand load, the intermittent demand load, the additional demand load imposed on the system during use of certain kits, the battery charging rate, and the normal running time of the vehicle between starts. The limiting factors are, of course, the costs of the larger generating system and the limited space available for larger units and associated equipment.

To provide the capacity for cold-weather starting, to reduce the size and weight of the generating equipment, and to provide compatibility with other military vehicles and the static power source, the electrical system must be designed for 24-v dc.

The dynamic power source may be either a generator or an alternator whose output is rectified to provide direct current.

A military 25-amp generator and its respective regulator is presently specified for the M151. An alternator kit, including a 100-amp alternator, regulator, mounting brackets, and associated equipment, is also installed whenever radio communication equipment is specified unless the power requirements are very low. These units are waterproof and fungus and corrosion resistant. They

TABLE 27

Multiple Radio Installation and Power Requirements for ¼-ton Truck[a]

Code	Radio sets	Approximate power required, amp
1	VRQ-1 + GRC-19	8 + 18 = 26
2	GRC-19 + GRR-5 + VRC-18	18 + 2 + 4 = 24
3	GRC-19 + GRR-5 + VRC-34 or GRC-87	18 + 2 + 3 = 23
4	GRR-5 + VRQ-3 + VRC-24	2 + 8 + 11 = 21
5	GRC-106 + GRR-5 + VRC-34 or GRC-87	13 + 2 + 3 = 18
6	VRC-24 + GRC-3 to 8	11 + 6 = 17
7	VRC-18 + VRC-24 + GRR-5	4 + 11 + 2 = 17
8	GRC-106 + VRC-47	13 + 3.3 = 16.3
9	GRC-106 + VRC-46	13 + 2.5 = 15.5
10	GRC-106 + GRR-5	13 + 2 = 15
11	VRC-46 + VRC-24	2.5 + 11 = 13.5
12	VRQ-3 + VRC-34 or GRC-87	8 + 3 = 11
13	VRQ-3 + PRC-10	8 + 3 = 11
14	VRQ-3 or 3 + GRR-5	8 + 2 = 10
15	VRQ-1 + R110/GRC	8 + 1.5 = 9.5
16	GRC-3 + PRC-8	6 + 3 = 9
17	GRC-7 + PRC-10	6 + 3 = 9
18	GRC-3, 5 or 8 + VRC-34 or GRC-87	6 + 3 = 9
19	VRC-10, 17 or 18 + VRC-34 or GRC-87	4 + 3 = 7
20	GRC-8 + GRR-5	5 + 2 = 7
21	VRC-46 + VRC-34	3.3 + 3 = 6.3
22	VRC-47 + GRC-87	3.3 + 3 = 6.3
23	VRC-17 + GRR-5	4 + 2 = 6
24	VRC-6 + VRR-6	3 + 3 = 6
25	VRC-9 + VRC-9 or 10	3 + 3 = 6
26	VRC-9 + PRC-9	3 + 3 = 6
27	VRC-10 + PRC-10	3 + 3 = 6
28	VRC-8 + VRC-9	3 + 3 = 6
29	PRC-8 + VRC-9	3 + 3 = 6
30	PRC-9 + VRC-34	3 + 3 = 6
31	VRC-8 + VRC-8	3 + 3 = 6
32	VRC-10 + VRC-10	3 + 3 = 6
33	VRC-8 + PRC-8	3 + 3 = 6
34	VRC-6 + VRR-6	3 + 3 = 6
35	VRC-46 + VRC-47	2.5 + 3.3 = 5.8
36	VRC-46 + VRC-46	2.5 + 2.5 = 5
37	GRR-5 + VRC-34	2 + 3 = 5
38	VRC-9 + GRR-5	3 + 2 = 5
39	GRC-87 + GRR-5	3 + 2 = 5
40	VRC-46 + GRR-5	2.5 + 2 = 4.5
41	VRC-46 + VRC-53 or GRC-125	2.5 + 0.7 = 3.2
42	VRC-46 + GRC-125	2.5 + 0.7 = 3.2

[a]Receive-transmit ratio 5 to 1 except as noted, i.e., TWX service or retransmission.

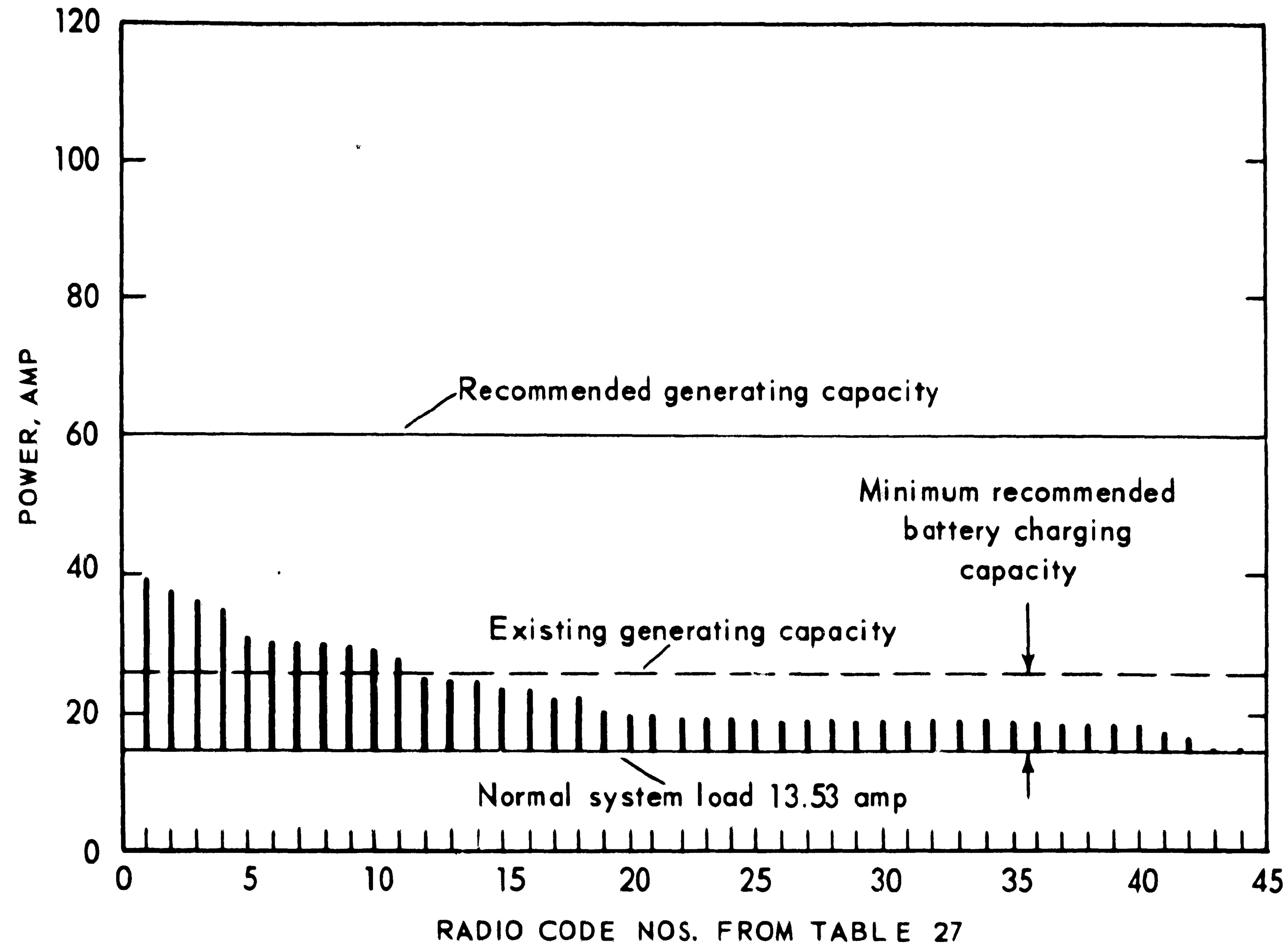

Fig. 7—Power-Demand Chart for Various Double Radio Installations

Normal nighttime operation.

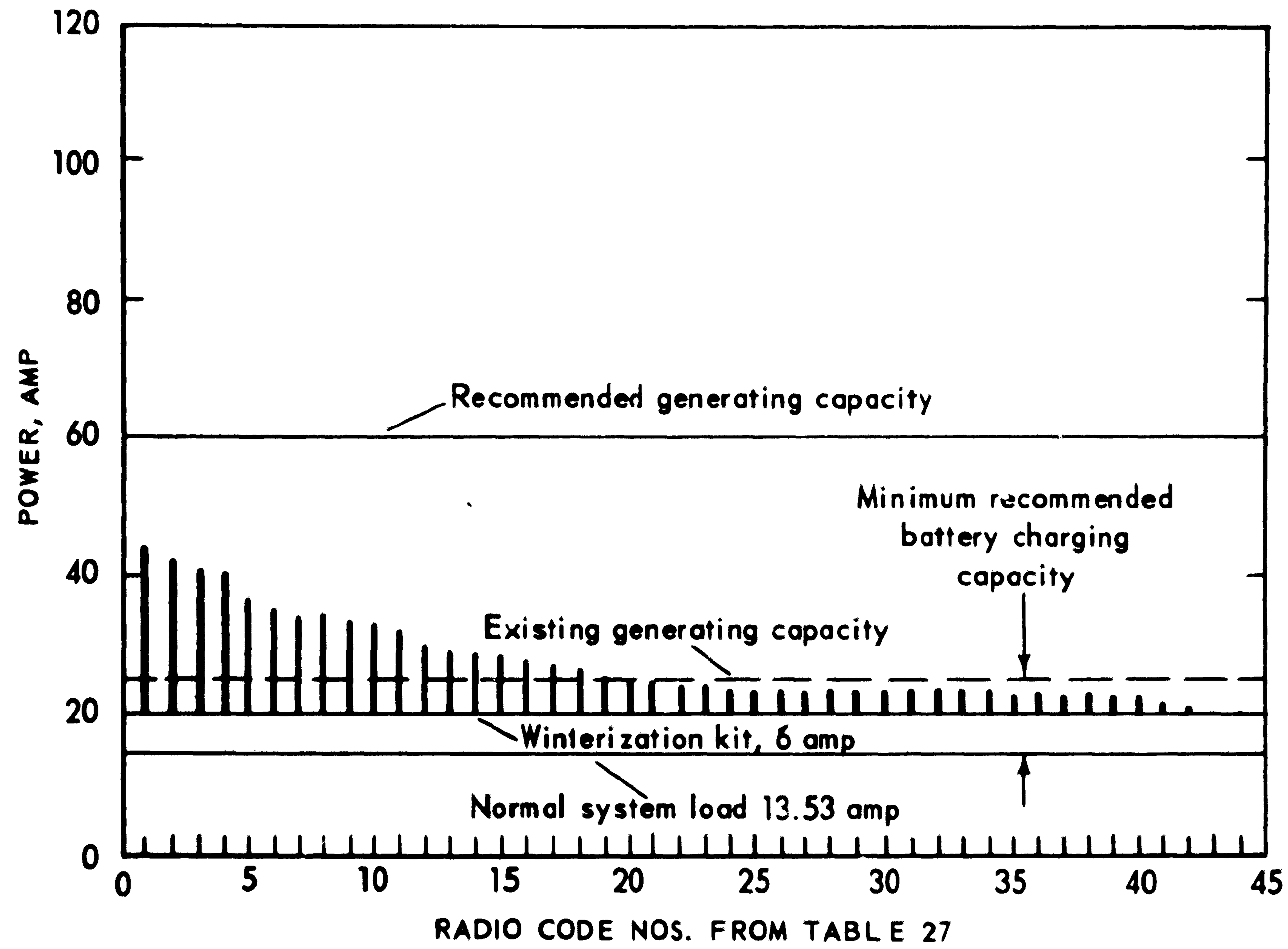

Fig. 8—Power-Demand Chart for Various Double Radio Installations plus Winterization Kit

Normal nighttime operation.

will also meet the military requirements for shock, vibration, and radio-interference suppression.

A 60-amp alternator Army Part No. 10929868 conforming to MIL-G-46795 (MO) has been recently approved for military use. This alternator has the rectifiers and regulators self-contained. Since the endurance tests have indicated that these units will have long life, it is anticipated that no maintenance will be incurred other than replacement of the complete unit. Repair of failed units presumably would be subcontracted when a sufficient number has been accumulated. From the power analysis discussed in the electrical section, it follows that the 60-amp alternator will supply the power requirements of both the vehicle system load and the radio communication equipment except the previously discussed radio-teletype sets ANVSC-1, ANVRC-29, and GRC-46, which have very low density. The new 60-amp alternator costs more initially, but since the 100-amp alternator kit will not be required on all the vehicles the cost savings will be significant. For example, assume that one vehicle out of five will be furnished with the 100-amp alternator kit for the present M151. The costs shown in the accompanying tabulation are close approximations of the actual cost.

Generating system components	Cost for 100 vehicles	
Present M151		
25-amp generator	\$ 58.70 × 100 =	\$ 5,870
Voltage regulator	20.40 × 100 =	2,040
100-amp alternator kit furnished on 20% density	440.00 × 20 =	8,800
Total for 100 vehicles		\$16,710
Proposed $^1/_4$-ton truck		
60-amp alternator with self-contained rectifiers and regulator	150.00 × 100 =	15,000
Total saving for 100 vehicles		\$ 1,710

The saving of \$1,710.00 for 100 vehicles represents the initial costs only. If the costs were projected on replacement parts and labor, the total cost savings would increase substantially. Therefore it is recommended that the 60-amp alternator should be incorporated on all $^1/_4$-ton trucks in lieu of the 25-amp dc generator and the 100-amp alternator kit now provided.

Starter

The military starter is waterproof and fungus and corrosion resistant. It is designed for the engine now specified in the $^1/_4$-ton truck. A commercial starter that would interchange with the present military starter is not available now. To attempt to provide a commercial starter would not result in the maximum cost savings, since limited production and tooling would be factors to consider. By relaxing the waterproofing requirements on the present military starter a cost saving of approximately \$7.50 can be achieved.

If an alternative engine is selected, the starter normally specified for this engine could be modified with an estimated cost saving of $11 as compared to the cost of the military starter.

It is recommended that the present military starter be retained but modified to splashproof if the deep-fording kit is not required, provided the present engine will be specified.

Communication

The present M151 ¼-ton truck can mount the current radio communication equipment, but the truck's generating capacity is insufficient to provide power for many of these radio sets. In order to satisfy these power requirements a 100-amp alternator kit must be provided.

A 60-amp alternator was discussed previously, and it is recommended that the 60-amp alternator be incorporated in all ¼-ton trucks thus providing these vehicles with the generating capacity necessary to satisfy the power requirements of most of the current radio sets without the use of auxiliary kits.

VEHICLE BODY

Introduction

Considerable effort has been made to develop vehicle bodies of noncorrosive materials. Plastics have been used with some success. The advantages of these plastics are lower initial cost of tooling, greater flexibility in design, and excellent resistance to corrosion. The disadvantages of these plastics are higher material and production costs, rapid change of material physical properties with temperature changes (e.g., brittleness in cold weather, low tensile strength in warm weather), difficulty of attaching metal brackets or components to body, and special repair equipment required.

Expanded Royalite, which is a thermoplastic structure laminate consisting of a light core covered by layers of rubberlike material that has good resistance against abrasion was considered for use as a body material. The laminate is chemically bonded under heat and pressure. The material resists corrosion when exposed to normal elements and weather, and coloring can be an integral part of the exposed material. The material has good sound deadening and insulating characteristics. It is contour formed over a mold or die by heating and drape forming and/or air evacuation. During the heating process the laminate becomes limp and the core expands to final thickness. After a short (10 min) cooling period the formed material can be removed from the mold.

Expanded Royalite has been used in limited applications for small components such as engine covers and fenders. Larger applications include boat hulls and small trailer bodies. Experimentation is continuing with automobile bodies and truck cabs. However, all the above-mentioned applications must be considered still in the experimental stage until adequate service life can be accumulated to assess its durability. The material has been successfully used for components that require a minimum of hardware attachment points. It is felt, however, that there is a great lack of experience with this material for use in larger components such as complete vehicle body assemblies. A vehicle as-

sembly requires a great many attachment points for heavy components such as engine, transmission, and suspension system in addition to the many smaller components.

The cost of the raw material is quite high, and the cost of labor and material to properly attach metal brackets or components to the Royalite body is considerably higher than the cost to attach these items to the steel body.

It is therefore recommended that Royalite material not be considered for use in the vehicle body until the present state of the art for this material has advanced sufficiently through experimentation and successful application of smaller and less complex components.

Light-gage aluminum has been used primarily to save weight and resist corrosion. Sheet aluminum alloys recently developed, such as the 5000 series, contain magnesium, which is weldable and resists corrosion in salt spray or water. The tensile strength of this material is lower than that of steel; therefore a heavier gage must be used to obtain strength corresponding to that of steel. Sheet aluminum can be handled easily during fabrication but spot or seam welding by a metallic inert-gas or tungsten inert-gas process is much more difficult. Acceptable fabrication of aluminum requires much more rigid quality control than fabrication for steel. Therefore it is recommended that mild steel be continued for use in fabricating the body of the ¼-ton utility truck. The present M38A1 or M151 steel body has not encountered serious deterioration due to corrosion. The costs of these steel bodies have been reasonable, and some additional cost savings can be realized by reducing the number of spot welds and by a redesign of some of the more complex shapes.

Control System

The control system for the M151 is designed to provide smooth control movements by the operator. It is functionally simple and utilizes automotive methods of braking, clutching, shifting, steering, and engine control.

The shifting is accomplished manually, and the placement of the shift levers (depending on the design of the transmission) is located to present a control pattern that is safe, easy, and comfortable.

The clutch and brake levers, of the suspended type that requires minimum effort by the operator, are placed to provide easy manipulation. They require no maintenance other than minor adjustments.

The bell cranks used to interconnect the controls and levers are equipped with sintered brass bushings, which do not require lubrication. Loose-fitting connecting rods are used to interconnect the bell cranks with the actuating levers. These rod ends do not require lubrication and although some wear will be experienced because of the lack of bushings, they are expected to last the life of the vehicle.

The clutch, brake, and throttle controls are located in such a manner that they can be operated easily without the driver's having to assume uncomfortable body angles. The foot throttle control or accelerator pedal assembly, including the connecting linkage and bell cranks, is quite complicated and can be simplified with an estimated reduction in cost of $4 per assembly. The simplified assembly would be equally as reliable as the present system and would eliminate the special rubber boot now required during deep fording operations.

The instrument panel is located in the center of the dashboard, and the operator is required to glance to the right to observe the instruments. It would be desirable to locate the instrument panel directly in the operator's line of vision. However, since the steering wheel and post assembly would interfere with his view of the instruments, it is recommended that the instrument panel be retained in its present position.

The choke and hand-throttle controls are located conveniently on the dash and are simple in design. The throttle control could be eliminated, but for cold-weather operation and for extended periods of radio operation, the hand throttle is required to keep the engine operating above idle speed.

The brake master cylinder is positioned conveniently for servicing and is of conventional automotive design. The brake lines are made of automotive type III steel and covered with conduit Army Part No. 17-C-18035-40 except at connection points. It is felt that stainless-steel tubing would serve this function in a safer and more reliable manner and costs would be comparable. However, because of the absence of any known failures of the existing brake line, it is recommended that these brake lines be retained.

The parking brake control is located conveniently near the shift control, thus assuring that the control movements are interrelated. The transmission is designed to incorporate the parking brake drum on the aft end of the transmission output shaft, thus providing an effective short-coupled brake arrangement. No special maintenance is required other than minor adjustments of the brake band.

The steering of the M151 vehicle is accomplished simply and economically through use of a worm and double roller in the steering-gear assembly and with conventional parallelogram-type linkage. Conventional automotive-type tie-rod ends are used, which require greasing periodically. Tie-rod ends are being developed that incorporate Teflon (tetrafluoroethylene) fiber inserts. The proposed Teflon rod end is much simpler in design and requires no lubrication. Engineering tests have been made comparing the frictional characteristics of an automotive ball-and-socket suspension joint made with fabric inserts of Teflon with a conventional ball joint. These Teflon inserts provide an extremely low coefficient of friction, improved ride, and freedom from lubrication. Further study is required to determine their adaptability to the ¼-ton truck, but they should be considered in the preliminary design. They are already in use on many military vehicles where standard rod ends are required for control functions such as shifting and braking. It is recommended that the conventional tie-rod ends be retained for steering purposes because of their availability and low cost but with possible substitution of the new improved tie-rod ends as they become available (see Figs. 9 and 10).

Mobility

Improving the mobility of the present M151 by using a larger tire was considered. It is generally accepted that the larger the tire the more mobile the vehicle. A tire one or two sizes larger in diameter and cross-sectional width would increase the vehicle mobility to a limited extent. This could be incorporated into the present vehicle with minor modifications. Goodyear Tire Company for the past few years has been developing tires having large cross-sectional widths

to improve mobility. They have determined through tests that a tire having a large footprint and air pressure of approximately 6 lb would negotiate most muddy or swampy terrain. Some of these tires have 12-, 16-, and even 24-in. cross-sectional diameter. These large tires envelop sharp objects such as rocks and are surprisingly resistant to puncture. Incorporating these tires in a ¼-ton utility truck would substantially add resistance to steering and hence require power steering. This would increase the cost of the vehicle not only

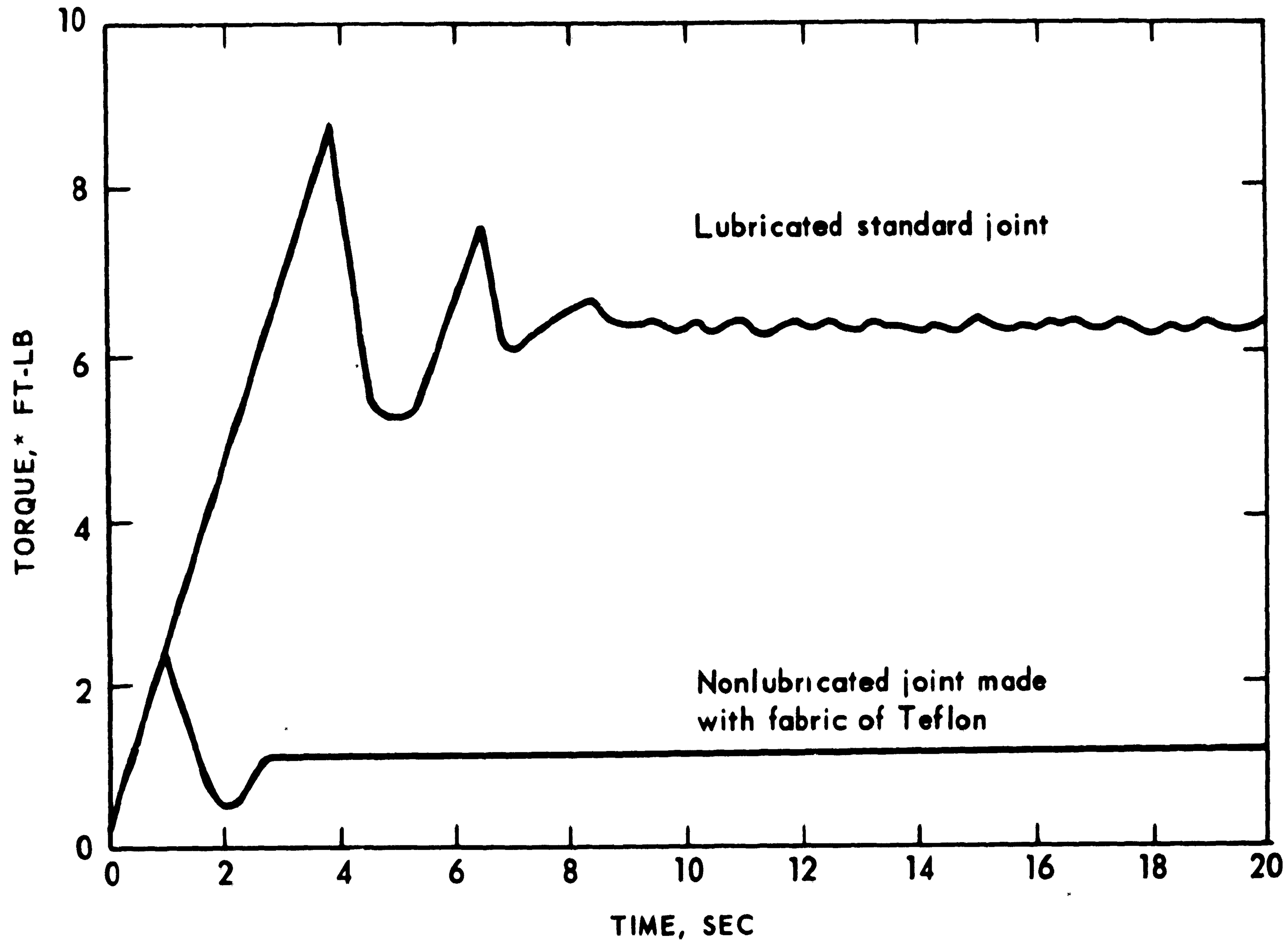

Fig. 9—Frictional Performance of Automotive Suspension Joints, 1000-lb Compression Load[a]

* ½ ft/min

for the power-steering components but also for the cost of the tire. In addition these tires would require a larger wheel well, particularly for the front wheels. This would present a design problem since it decreases the size of the engine compartment. In addition, special wheels would have to be designed and would complicate the suspension system. It is therefore doubtful that the larger tires would increase mobility sufficiently to warrant the additional complexity of vehicle design or the additional cost for this increase in mobility.

Mufflers

During the course of our studies several facts have presented themselves pertaining to muffler costs and quality life. These facts are based on the authors' previous experience with vehicular exhaust systems and on the opinions of several experienced muffler manufacturers.

The muffler that has been supplied for use on the M151 truck, Army Part No. 7331260, is fabricated from commercial-quality cold-rolled steel with no

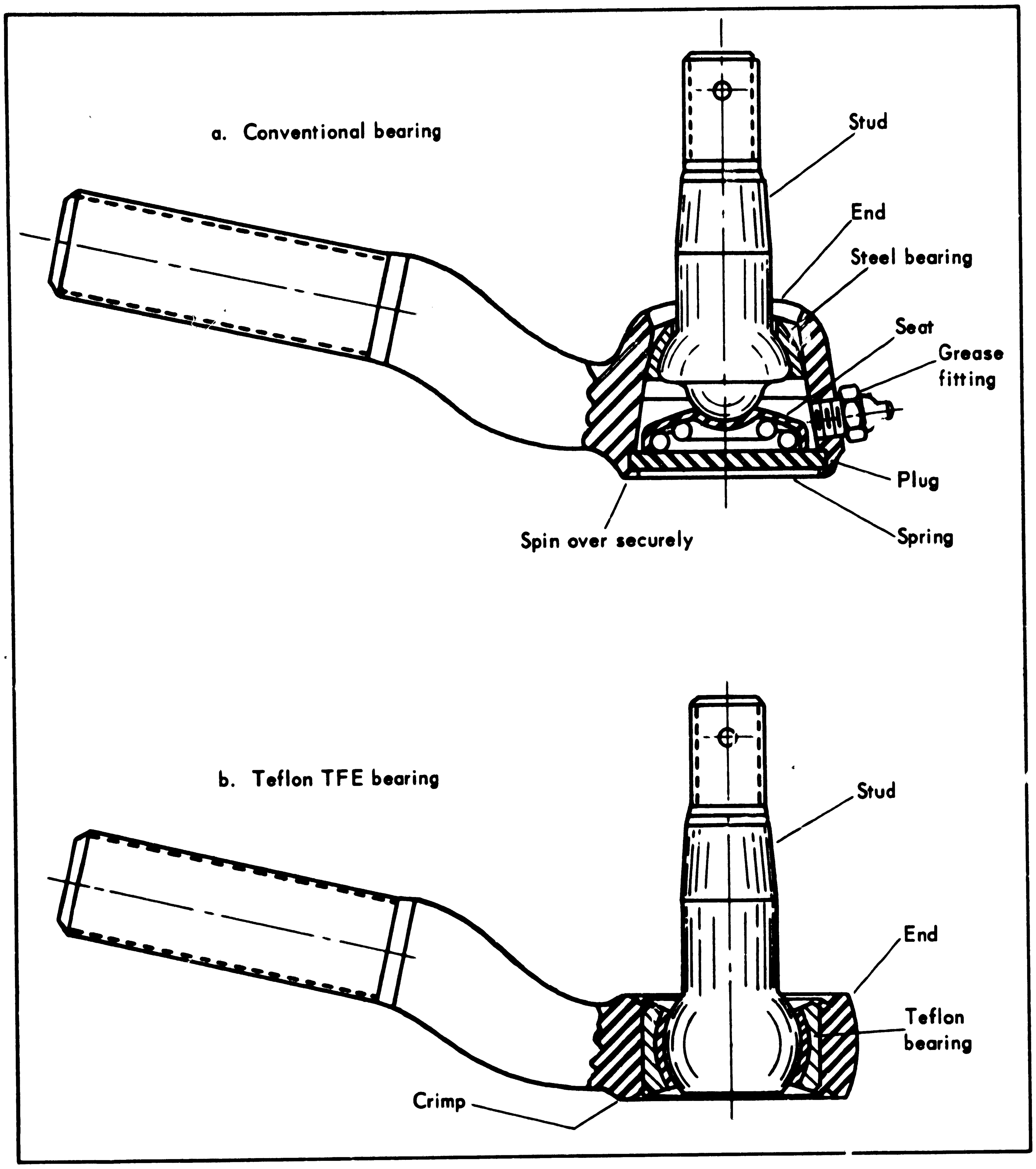

Fig. 10—Rod End

protective finish or coating applied on external surfaces. The manufacturer who has been supplying these mufflers to the military also manufactures a similar muffler fabricated from aluminized steel for use on a commercial version of the ¼-ton truck. It is both the manufacturer's and the authors' opinion, based on a vast backlog of laboratory and field tests and reliability experience in user operation, that an aluminized steel muffler has a life-expectancy increase of 75 percent for a cost increase of 15 percent over that of a muffler manufactured of commercial-quality cold-rolled steel with no protective coating applied. A

new stainless-steel muffler, which has been developed by several manufacturers, will show a life increase of 200 percent at a cost increase of 50 percent over a commercial unprotected steel muffler.

The present Mil Specs that control the manufacturing quality of the muffler account for an increased unit cost over similar parts used in commercial vehicles of this type. One item in the specifications is the water leakproof test. This, of necessity, requires arc welding and/or continuous seam welding in lieu of spot welding or mechanically assembling component parts. Commercial practice specifies an air test of 6 lb/sq in. internal pressure with an allowable leakage rate of 3 cu ft/min.

The present flanged connections of the exhaust and tail pipes, rather than the slip-type overlap fit with U-bolt-type clamping used commercially, increases costs considerably. Any attachment of an extension pipe integral to the muffler assembly naturally increases the cost of the muffler. It is much less costly, however, to eliminate the pipe extension from the muffler assembly and add this length onto the exhaust or tail pipe.

Included in the specifications for many items is the note, "must be manufactured exactly to print." This restricts competitive bidding since all major manufacturers have methods of fabricating parts, perforating tubes, drawing heads, punching baffles, attaching parts, etc., which vary in many ways but accomplish the same end. Manufacturers of commercial vehicles are accustomed to approve several sources with several fabricating design options, provided of course, they meet established standards. This allows a muffler or other component manufacturer to submit his best cost using his own methods and equipment.

FORDING AND SWIMMING CAPABILITIES OF THE 1/4-TON UTILITY TRUCK

Deep-Water Fording Capabilities

The present M151 vehicle has deep-water fording capabilities by the addition of a special kit. To permit use of this kit, special adapters and other provisions are incorporated on all vehicles with a resultant increase in cost. In general, before the vehicle may deep ford, the following requirements must be met:

(a) The entire electrical system must meet the military waterproof specification, which includes submergence.

(b) The exhaust system must be completely watertight.

(c) The air-intake system including the air filter must be watertight.

(d) All vent lines must be watertight.

(e) The fording kit must be installed properly.

To modify a standard military vehicle to accept a fording kit, the following items must be considered: (a) hole provided in hood for kit air-intake tube, (b) special tailpipe with flange to adapt to kit exhaust tube, (c) welded muffler and special clamps to achieve watertightness, (d) special fuel-tank cap with an air vent that can be closed during fording, (e) special fording valve with associated vent lines installed on all vehicles, (f) miscellaneous mounting holes and

nuts, (g) carburetor with special float chamber ventilation provisions, (h) waterproof rather than splashproof starter, (i) waterproof rather than splashproof generator regulator for deep fording, (j) special radio-suppressed and waterproof ignitor, (k) special high-temperature-resistant underwater vents and gaskets, (l) waterproof cabling and connectors throughout vehicle, (m) waterproof instruments and indicator lights, and (n) waterproof rather than splashproof activating units and switches.

A user survey was made to evaluate this requirement. It was determined that the frequency with which these vehicles were subjected to deep-water fording was nil. Most vehicle commanders found deep-water fording impractical, and other means were devised to accomplish this mission. In addition there was a strong probability that the vehicle would be immobilized on entering or climbing out of rivers. In order to negotiate river banks these vehicles would require a winch to permit the vehicle to extricate itself, which would further increase the cost of the vehicle and add vehicle weight. It would then be logical to eliminate the deep-water fording requirements, thereby saving the cost of the kit and cost and increase of maintainability on the basic vehicles.

An itemized cost list of the special adapters and other provisions that must be included on all vehicles to permit use of this kit follows:

Provision required by kit	Estimated additional cost, dollars
Provide a hole in hood for air-intake tube; requires several press operations	0.75
Provide a special tail pipe with flange to adapt to exhaust tube	2.80
Provide a welded muffler and special clamps to achieve water-tightness	2.40
Provide a special fuel-tank cap so air vent may be closed during fording	0.15
Provide a special fording control valve, which is mounted on the intake manifold with all the vent lines connected to it	1.95
Provide a brake master cylinder, which must be connected to a vent pipe during fording	None
Provide miscellaneous mounting holes and nuts to connect various brackets	0.65
Provide a carburetor with special float-chamber ventilation provisions for deep-water fording, thus requiring the use of a specially designed carburetor	11.30
Provide a waterproof rather than splashproof starter	6.75
Provide a waterproof rather than splashproof generator and regulator for deep fording	24.70
Provide a special radio-suppressed and waterproof rather than splashproof igniter for deep fording	2.40
Provide special high-temperature resistant underwater vents and gaskets	0.85
Provide waterproof rather than splashproof cabling and connectors throughout the vehicle to meet the deep-fording requirements	4.60
Provide waterproof rather than splashproof instruments and indicator lights for deep fording	2.70
Provide waterproof rather than splashproof activating units and switches for deep fording	6.80
Total	68.80

Swimming Capabilities

A study was made to determine the feasibility of incorporating swimming capabilities in the $\frac{1}{4}$-ton utility truck with a water speed up to 4 mph. Since this vehicle is very dense for its size a preliminary buoyancy and trim study was made to determine if the vehicle having its present or modified configuration would have satisfactory trim and stability characteristics. It was assumed that the modifications required to make the vehicle body or hull would add approximately 10 percent to the vehicle weight. This weight was evenly distributed about the present vehicle center of gravity. The analysis indicated that the vehicle's static waterline was not ideal but could be acceptable if all other vehicle characteristics remained satisfactory.

The calculations were based on enclosing the engine compartment as well as the driver's and cargo compartments. This would leave the engine and its accessories dry, and the cooling air would enter and leave the compartment through grill openings at the top. The vehicle would be quite stable, and its maximum list would be limited to the height of the freeboard. This freeboard is assumed to be $10\frac{3}{4}$ in.

A total of three trim and stability studies was made, each study having a different vehicle concept configuration. The first study considered using the present M151 without relocating any major components. The second study considered moving the engine, transmission, and cooling system as far aft as possible without modifying the present driver's cab. This concept would improve the location of the center of gravity. The third study considered a concept that would place the driver's cab completely forward, and the engine compartment as far aft as possible, and leave the remaining center portion of the vehicle for cargo. This concept would be most favorable for level trim when the vehicle was empty or loaded. All three concepts affect presently designed components in varying degrees. The last concept affects component design most drastically.

This redesign may force the vehicle designer to give up many of the shelf items normally available to him, and cost most certainly would be affected. The cooling system would have to be isolated from the engine compartment if the radiator were to be used as a keel cooler. If the radiator were placed within the engine compartment, ducts would be required in the top of the vehicle for the cooling air. Vehicle sides would have to be raised considerably to obtain a safe freeboard height, and since this vehicle is dense for its size, it would tend not to rise or fall with the surrounding waves. For the safety of the vehicle and its personnel, a bilge pump would have to be provided. Experience has shown that calm water becomes quite choppy when a number of vehicles make simultaneous crossings. A watertight hull or body would provide dry compartments for many of the components and therefore waterproofing requirements could be deleted. The vehicle's lights should be placed above the waterline, and the sides of the cab would of necessity be raised. This would make it more difficult for personnel entering and leaving the cab.

Based on previous tests, propulsion of the vehicle in water by means of wheels only would propel the vehicle at a speed no greater than $1\frac{1}{2}$ mph. If the body of the vehicle were designed with streamlining to resemble a ship's hull, the vehicle water speed would be increased marginally. A more efficient method of propulsion would be through the use of a water jet or a marine propeller. Either of these two methods would greatly complicate the controls, increase

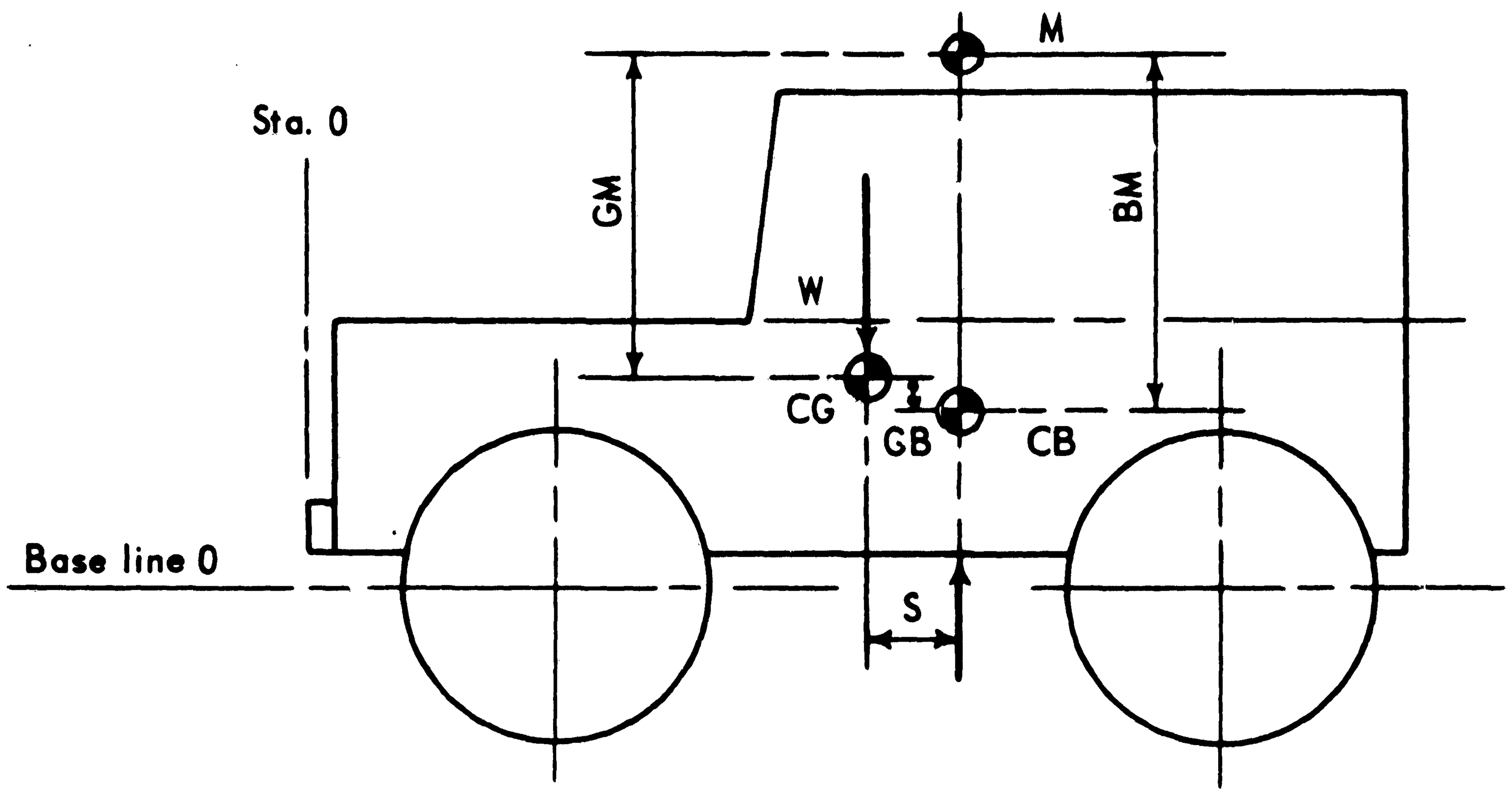

Fig. 11—Trim Nomenclature for Floating and Amphibious Concept ¼-ton Vehicle

W = weight of vehicle
M = metacenter
CB = center of buoyancy
CG = center of gravity
BM = distance from M to CB
GM = distance from M to CG
GB = distance from CB to CG
S = horizontal distance from CB to CG

$$\text{BM} = \frac{\text{moment of inertia of water plane in ft}}{\text{volume in cu ft (displacement)}}$$

$$\text{GM}^{a} = \text{BM} \pm \text{GB}$$

$$\text{Moment to alter trim 1 in.} = \frac{\text{GM} \times \text{displacement, lb}}{\text{length of water plane} \times 12\text{, ft}}$$

$$\text{Total trim} = \frac{\text{S} \times \text{W, lb}}{\text{moment to alter trim 1 in.}}$$

$$\text{Trim at each end} = \frac{\text{trim}}{2}$$

LCG = long. center of gravity
LCB = long. center of buoyancy
WP = water plane
I = moment of inertia of the WP about the fore and aft center line
Station 0[b] = the extreme forward perpendicular
VCG = vertical center of gravity
VCB = vertical center of buoyancy

[a]When CB falls below CG, GB is subtracted from BM; when CB falls above CG, GB is added to BM.
[b]Base line 0 is referred to as the horizontal center line of the axle = water line 0.

Trim Calculations for Vehicle without Relocation of Major Components

(Method of water propulsion: wheels only)
(3341-lb gross vehicle weight, 900-lb cargo)

Draft = 1.65 ft above base line 0
LCG = 5.70 ft aft of station 0
LCB = 6.06 ft aft of station 0
VCG = 0.86 ft above base line 0
VCB = 0.86 ft above base line 0
Trim lever(s) = 0.36 ft
Trim moment = 3341 lb × 0.36 ft = 1204 lb/ft
Length WP = 10.8 ft

$$I = \frac{bd^3}{12} = \frac{5 \times 10.8^3}{12} = 525 \text{ ft}^4$$

$$BM = \frac{I}{V} = \frac{525}{5353} = 9.80 \text{ ft}$$

GB = -0.185 ft

GM = BM - GB = 9.80 -0.185 = 9.615 ft

$$MT = \frac{W \times GM}{\text{length WP, ft,} \times 12} = 248 \text{ lb/ft}$$

$$TT = \frac{S \times W}{MT} = \frac{0.36 \times 3341}{248} = 4.8 \text{ in.}$$

$$\text{Trim at each end} = \frac{TT}{2} = \frac{4.8}{2} = 2.4 \text{ in.}$$

TABLE 28

Trim-Study Buoyancy Calculations for Vehicle without Relocation of Major Components, 3341-lb Gross Vehicle Weight

(Method of water propulsion: wheels only)

Water line	Volume, cu ft	Displacement, lb	LCB in. aft of station 0	Moments LCB, in.-lb	VCB in. above base line 0	Moments VCB, in.-lb
-16.00 – 6.00	13.25	827	59.7	49,376	2.54	2,103
6.00 – 11.00	14.60	910	76.8	70,370	8.48	7,723
11.00 – 16.00	15.58	972	76.8	74,635	13.49	13,113
16.00 – 19.75	10.10	632	77.2	48,790	17.8	11,249
Total	53.53	3341	72.7	243,171	10.3	34,188

Trim Calculations for Vehicle without Relocation of Major Components

(Method of water propulsion: wheels only)
(2441-lb curb weight)

$$
\begin{aligned}
\text{Draft} &= 1.25 \text{ ft above base line 0} \\
\text{LCG} &= 4.56 \text{ ft aft of station 0} \\
\text{LCB} &= 5.93 \text{ ft aft of station 0} \\
\text{VCG} &= 0.815 \text{ ft above base line 0} \\
\text{Trim lever(s)} &= 1.37 \text{ ft} \\
\text{Trim moment} &= 2441 \text{ lb} \times 1.37 \text{ ft} && = 3350 \text{ lb/ft} \\
\text{Length WP} &= 10.8 \text{ ft} \\
I &= \frac{bd^3}{12} = \frac{5 \times 10.8^3}{12} && = 525 \text{ ft}^4 \\
BM &= \frac{I}{V} = \frac{525}{39.1} && = 13.4 \text{ ft} \\
GB &= +0.165 \text{ ft} \\
GM &= BM + GB = 12.8 + 0.165 && = 12.965 \text{ ft} \\
MT &= \frac{W \times GM}{\text{length WP, ft,} \times 12} = \frac{2557 \times 12.965}{10.8 \times 12} && = 245 \text{ lb/ft} \\
TT &= \frac{S \times W}{MT} = \frac{1.39 \times 2557}{245} && = 14.46 \text{ in.} \\
\text{Trim at each end} &= \frac{TT}{2} = \frac{14.46}{2} && = 7.23 \text{ in.}
\end{aligned}
$$

TABLE 29

Trim-Study Buoyancy Calculations for Vehicle without Relocation of Major Components, 2441-lb Gross Vehicle Weight

(Method of water propulsion: wheels only)

Water line	Volume, cu ft	Displacement, lb	LCB in. aft of station 0	Moments LCB, in.-lb	VCB in. above base line 0	Moments VCB, in.-lb
-16.00 – 6.00	13.25	827	59.7	49,376	2.54	2,103
6.00 – 11.00	14.60	910	76.8	70,370	8.48	7,723
11.00 – 15.00	11.25	704	76.8	54,067	13.10	9,222
Total	39.10	2441	71.1	173,813	7.80	19,048

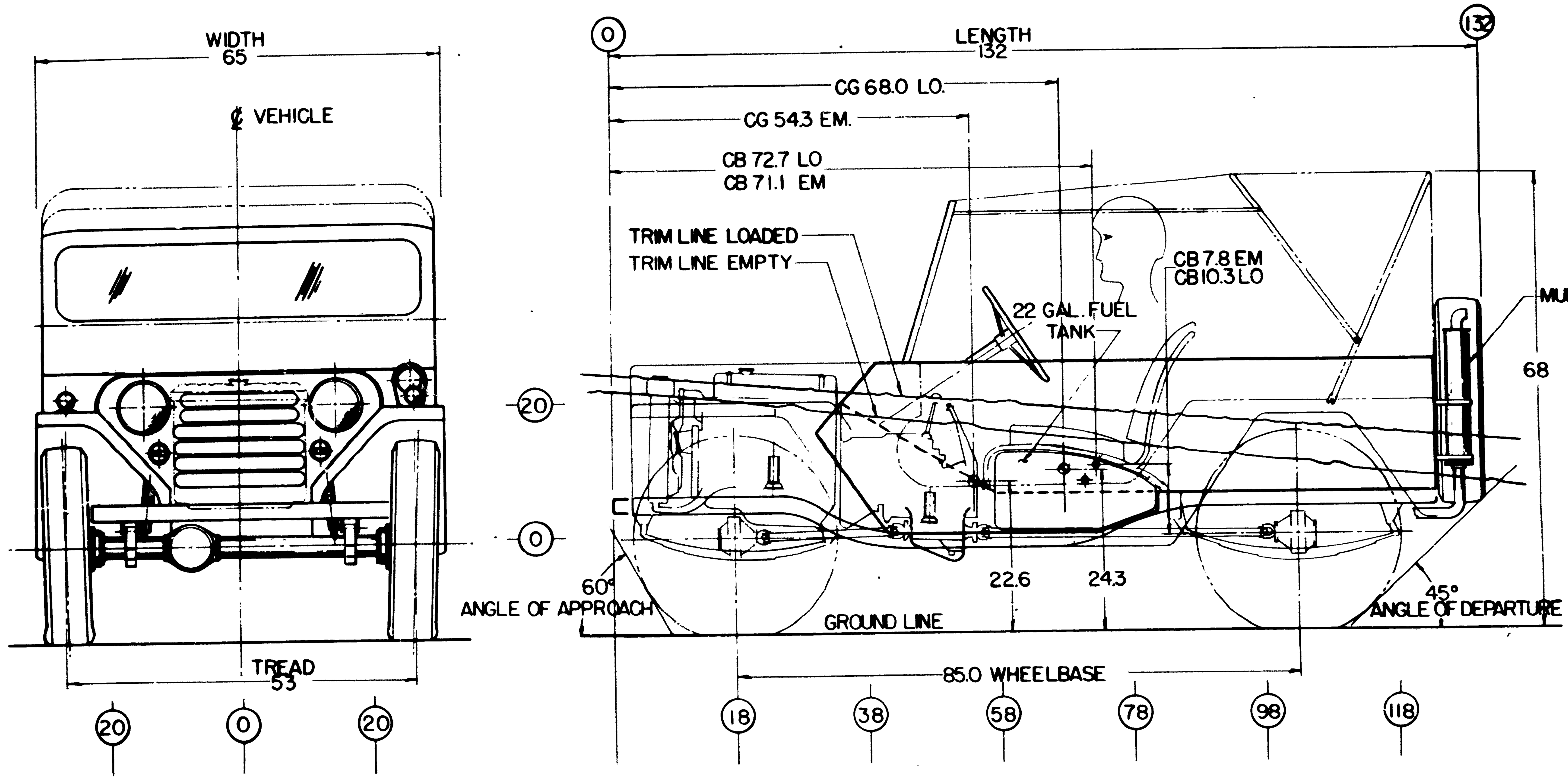

Fig. 12—Concept 1: Vehicle with Floating Capabilities without Relocation of Major Components

Method of water propulsion by wheels only.

Trim Calculations for Vehicle with Floating Capabilities with Relocation of Major Components

(Method of water propulsion: wheels only)
(3457-lb gross vehicle weight, 900-lb cargo)

Draft = 1.54 ft above base line 0
LCG = 5.77 ft aft of station 0
LCB = 5.44 ft aft of station 0
VCG = 0.857 ft above base line 0
VCB = 0.837 ft above base line 0
Trim lever(s) = 0.353 ft
Trim moment = 3457 lb × 0.353 ft = 1220 lb/ft
Length WP = 10.8 ft

$$I = \frac{bd^3}{12} = \frac{5 \times 10.8^3}{12} = 525 \text{ ft}^4$$

$$BM = \frac{I}{V} = \frac{525}{55.35} = 9.5 \text{ ft}$$

GB = +0.02 ft

$$GM = BM + GB = 9.5 + 0.02 = 9.52 \text{ ft}$$

$$MT = \frac{W \times GM}{\text{length WP, ft,} \times 12} = \frac{3457 \times 9.52}{10.8 \times 12} = 253 \text{ lb/ft}$$

$$TT = \frac{S \times W}{MT} = \frac{.353 \times 3457}{253} = 4.8 \text{ in.}$$

$$\text{Trim at each end} = \frac{TT}{2} = \frac{4.8}{2} = 2.4 \text{ in.}$$

TABLE 30

Trim-Study Buoyancy Calculations for Vehicle with Floating Capabilities with Relocation of Major Components, 3457-lb Gross Vehicle Weight

(Method of water propulsion: wheels only)

Water line	Volume, cu ft	Displacement, lb	LCB in. aft of station 0	Moments LCB, in.-lb	VCB in. above base line 0	Moments VCB, in.-lb
–16.00 – 6.00	15.30	954	56.4	53,747	3.1	2,958
6.00 – 11.00	16.25	1015	69.1	70,188	9.0	9,118
11.00 – 16.00	17.30	1083	69.7	75,760	14.0	15,162
16.00 – 18.50	6.50	405	64.0	25,920	18.25	7,391
Total	55.35	3457	65.3	225,615	10.05	34,629

Trim Calculations for Vehicle with Floating Capabilities with Relocation of Major Components

(Method of water propulsion: wheels only)
(2557-lb curb weight)

Draft = 1.17 ft above base line 0
LCG = 4.85 ft aft of station 0
LCB = 5.37 ft aft of station 0
VCG = 0.683 ft above base line 0
VCB = 0.643 ft above base line 0
Trim lever(s) = 0.625 ft
Trim moment = 2557 lb × 0.625 = 1600 lb/ft
Length WP = 10.8 ft

$$I = \frac{bd^3}{12} = \frac{5 \times 10.8^3}{12} = 525 \text{ ft}^4$$

$$BM = \frac{I}{V} = \frac{525}{40.97} = 10.57 \text{ ft}$$

$$GB = -0.04 \text{ ft}$$

$$GM = BM - GB = 10.57 - 0.04 = 10.53 \text{ ft}$$

$$MT = \frac{W \times GM}{\text{length WP, ft,} \times 12} = \frac{2557 \times 10.53}{10.8 \times 12} = 208 \text{ lb}$$

$$TT = \frac{S \times W}{MT} = \frac{.625 \times 2557}{208} = 7.7 \text{ in.}$$

$$\text{Trim at each end} = \frac{TT}{2} = \frac{7.7}{2} = 3.85 \text{ in.}$$

TABLE 31

Trim-Study Buoyancy Calculations for Vehicle with Floating Capabilities with Relocation of Major Components, 2557-lb Gross Vehicle Weight

(Method of water propulsion: wheels only)

Water line	Volume, cu ft	Displacement, lb	LCB in. aft of station 0	Moments LCB, in.-lb	VCB in. above base line 0	Moments VCB, in.-lb
-16.00 – 6.00	15.30	954	56.4	53,747	3.1	2,958
6.00 – 11.00	16.25	1015	69.1	70,188	9.0	9,118
11.00 – 14.00	9.42	588	69.7	40,983	13.0	7,644
Total	40.97	2557	64.5	164,918	7.72	19,720

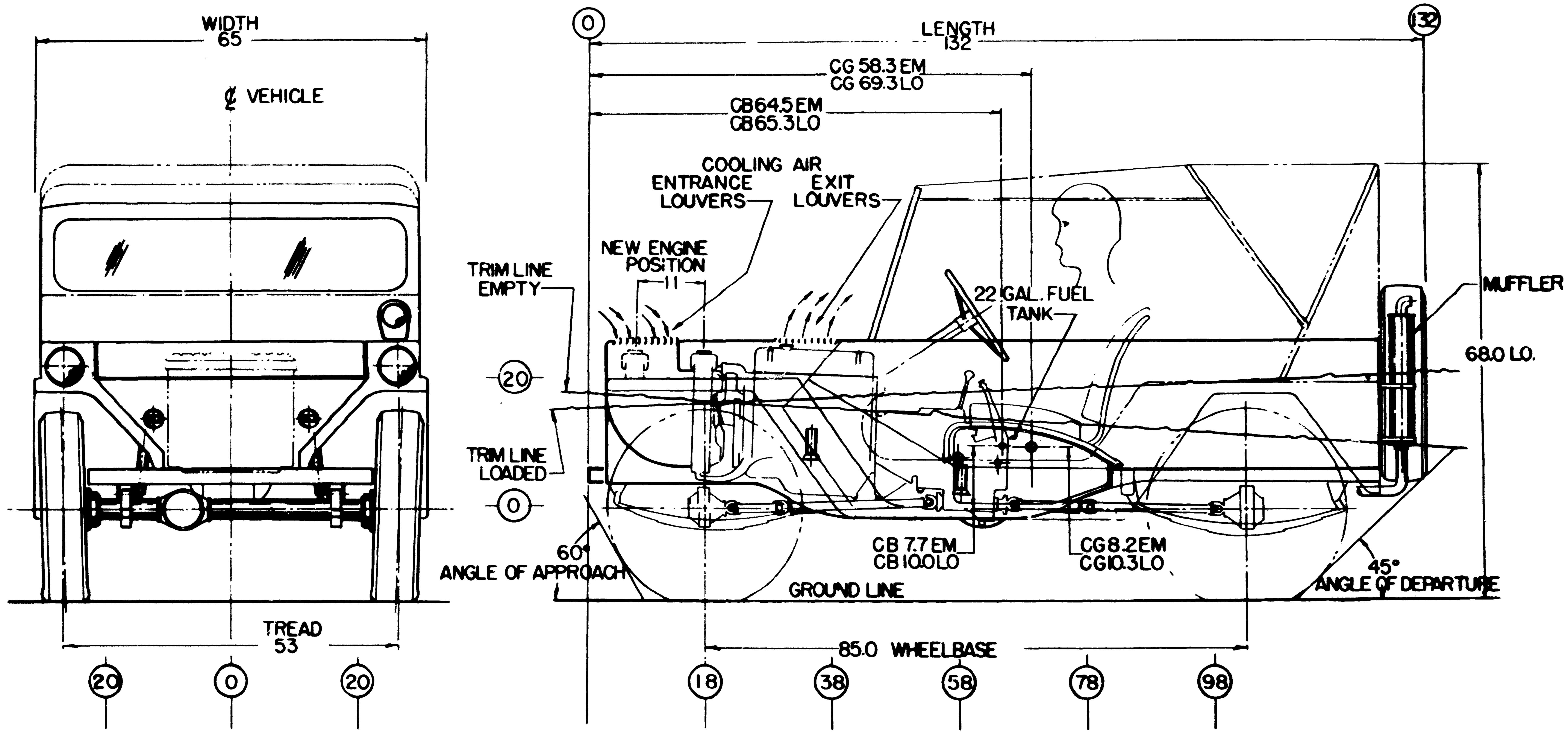

Fig. 13—Concept 2: Vehicle with Floating Capabilities with Relocation of Major Components

Method of water propulsion by wheels only.

Trim Calculations of Amphibious Vehicle

(Method of water propulsion: propeller or hydrojet)
(3574-lb gross vehicle weight, 900-lb cargo)

Draft	=	1.42 ft above base line 0		
LCG	=	6.70 ft aft of station 0		
LCB	=	6.71 ft aft of station 0		
VCG	=	0.857 ft above base line 0		
VCB	=	0.857 ft above base line 0		
Trim lever(s)	=	0.458 ft		
Trim moment	=	3574 lb × 0.458 ft		= 1590 lb/ft
Length WP	=	11.2 ft		
I	=	$\frac{bd^3}{12}$	$= \frac{5 \times 11.2^3}{12}$	$= 585\ ft^4$
BM	=	$\frac{I}{V}$	$= \frac{585}{57.25}$	= 10.2 ft
GB	=	0		
GM	=	BM ± GB		= 10.2 ft
MT	=	$\frac{W \times GM}{\text{length WP, ft,} \times 12}$	$= \frac{3574 \times 10.2}{11.2 \times 12}$	= 270 lb/ft
TT	=	$\frac{S \times W}{MT}$	$= \frac{0.458 \times 3574}{270}$	= 6.2 in.
Trim at each end	=	$\frac{TT}{2}$	$= \frac{6.2}{2}$	= 3.1 in.

TABLE 32

Trim-Study Buoyancy Calculations for Amphibious Vehicle, 3574-lb Gross Vehicle Weight, 900-lb Cargo

(Method of water propulsion: propeller or hydrojet)

Water line	Volume, cu ft	Displacement, lb	LCB in. aft of station 0	Moments LCB, in.-lb	VCB in. above base line 0	Moments VCB, in.-lb
17.00	57.25	3574	75.0	268,050	10.3	36,812

Trim Calculations for Amphibious Vehicle

(Method of water propulsion: propeller or hydrojet)
(2674-lb curb weight)

Draft = 1.20 ft above base line 0
LCG = 6.98 ft aft of station 0
LCB = 6.68 ft aft of station 0
VCG = 0.683 ft above base line 0
VCB = 0.683 ft above base line 0
Trim lever(s) = 0.585 ft
Trim moment = 2674 lb × 0.585 ft = 1562 lb/ft
Length WP = 11.0 ft

$$I = \frac{bd^3}{12} = \frac{5 \times 11.0^3}{12} = 555 \text{ ft}^4$$

$$BM = \frac{I}{V} = \frac{555}{42.7} = 13.0 \text{ ft}$$

$$GB = 0$$

$$GM = BM \pm GB = 13.0 \text{ ft}$$

$$MT = \frac{W \times GM}{\text{length WP, ft, } \times 12} = \frac{2674 \times 13.0}{11.0 \times 12} = 287 \text{ lb/ft}$$

$$TT = \frac{S \times W}{MT} = \frac{0.585 \times 2674}{287} = 5.5 \text{ in.}$$

$$\text{Trim at each end} = \frac{TT}{2} = \frac{5.5}{2} = 2.75 \text{ in.}$$

TABLE 33

Trim-Study Buoyancy Calculations for Amphibious Vehicle, 2674-lb Gross Vehicle Weight

(Method of water propulsion: propeller or hydrojet)

Water line	Volume, cu ft	Displacement, lb	LCB in. aft of station 0	Moments LCB, in.-lb	VCB in. above base line 0	Moments VCB, in.-lb
13.50	42.70	2674	73.0	195,202	8.2	21,927

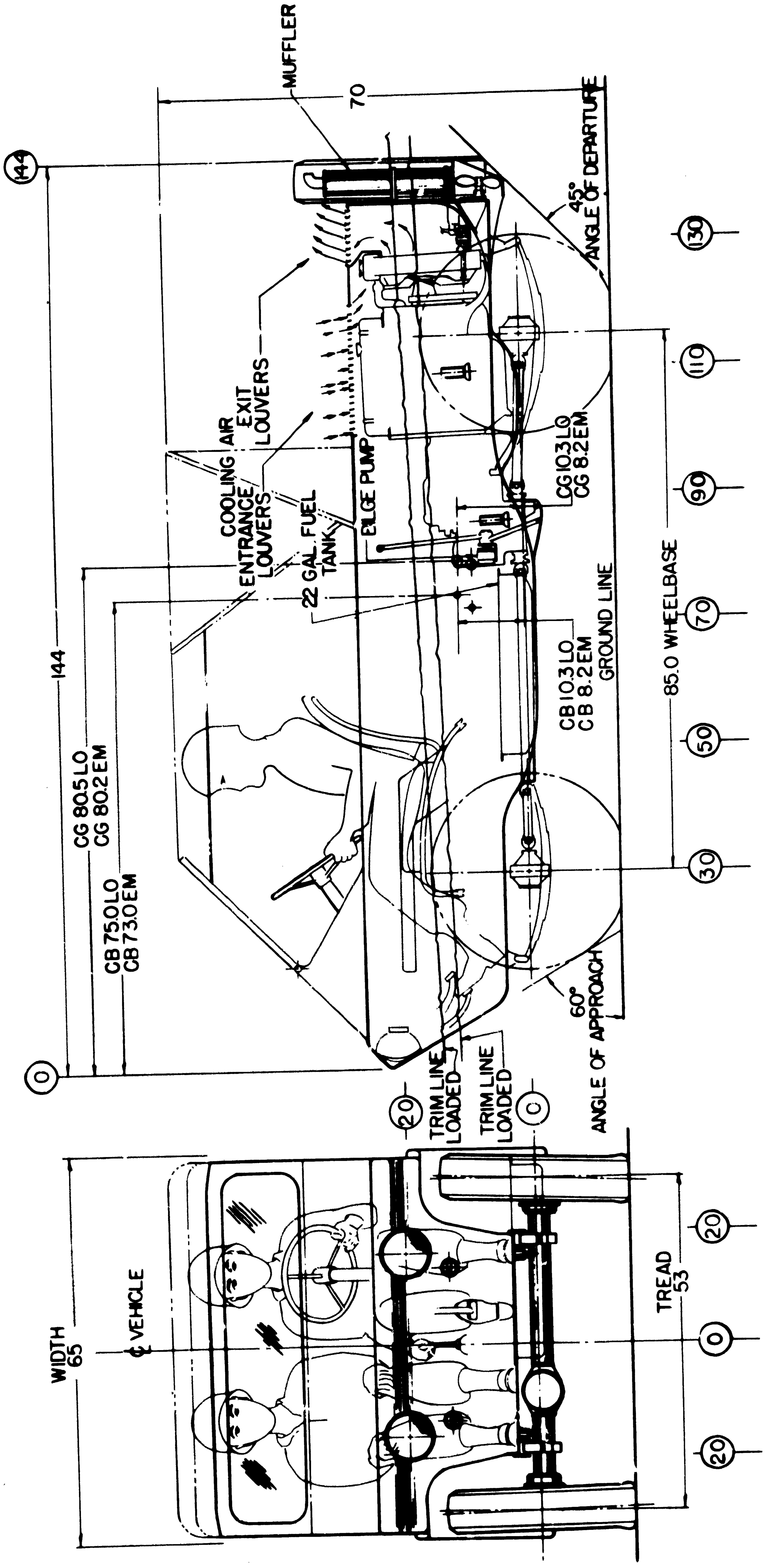

Fig. 14—Concept 3: Amphibious Vehicle

Method of water propulsion by propeller or hydrojet.

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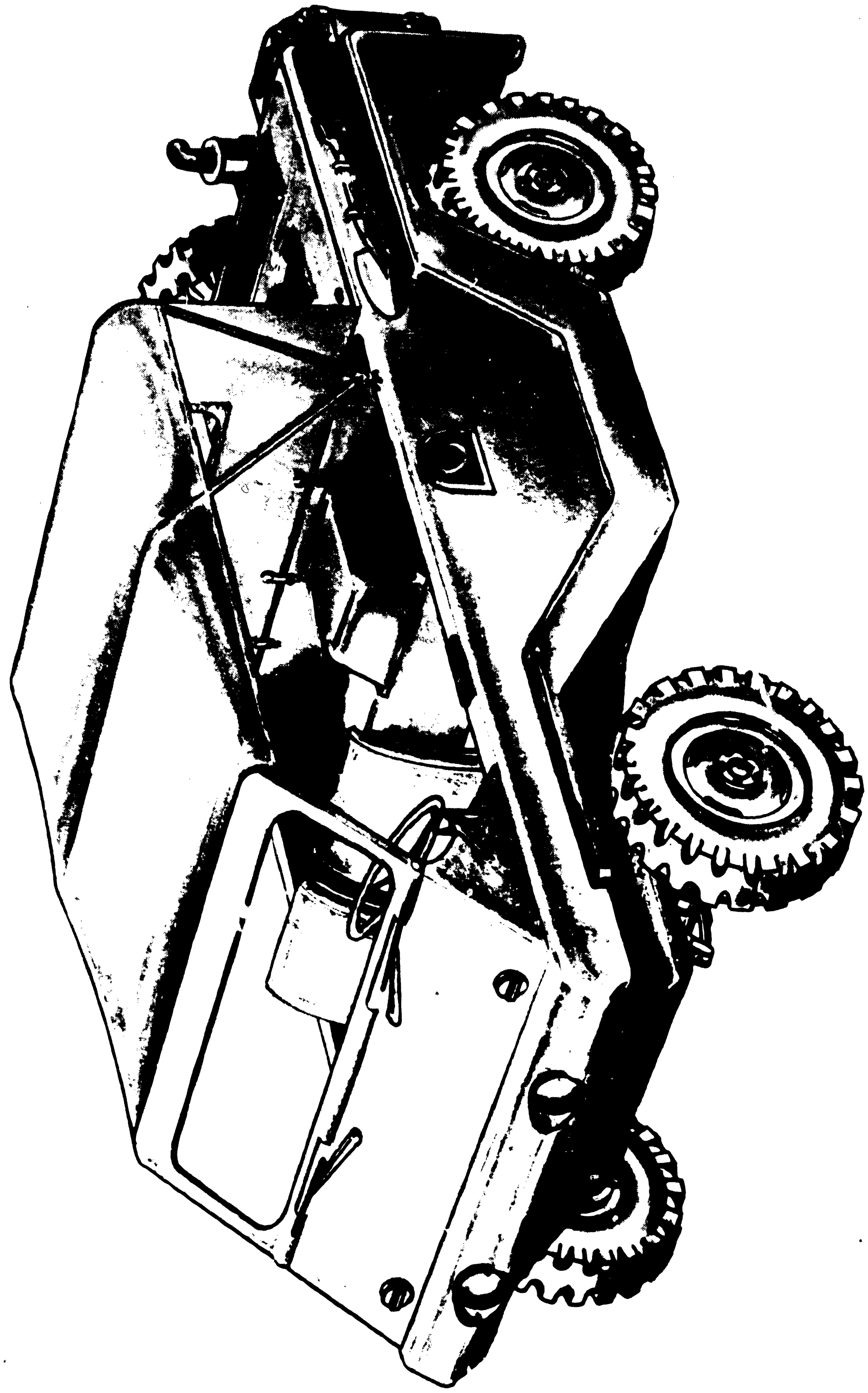

Fig. 15—Concept of Amphibious ¼-ton Vehicle

the vehicle weight, and result in additional maintenance. A ship-type hull would reduce the vehicle's angle of approach or departure and reduce land mobility. Vehicles having swimming capability must have sufficient water speed and thrust to enable the driver to control the vehicle. The minimum speed is considered to be 4 to 5 mph for this requirement, since most rivers have currents of this velocity.

Should the swimming capability be required for the ¼-ton utility truck, it is recommended that this be accomplished under a separate research and development program that would include model testing of various concepts and construction of a number of prototypes for evaluation.

Based on the considerations above, an acceptable ¼-ton truck with swimming capabilities would cost approximately 20 to 30 percent more than the present M151.

Trim and stability calculations for the three vehicle-concept configurations considered are shown on pages 66 to 76. Figure 11 illustrates the nomenclature used in the calculations. The trim and stability calculations along with the charted buoyancy values, which were taken at the indicated waterlines, are shown in loaded (gross) and empty (curb) vehicle-weight conditions (Tables 28 to 33) immediately preceding their respective vehicle-concept illustrations.

The loaded and empty vehicle trim line shown on the concept illustrations are for a static vehicle. Dynamically the trim lines would change considerably. The Vehicle Without Relocation of Major Components, concept 1 (Fig. 12), would undoubtably tend to "nose under" when underway. The Vehicle with Floating Capabilities, concept 2 (Fig. 13), would also have a tendency to "nose under" when underway, however not to the extent that vehicle concept 1 (Fig. 12) would. The Amphibious Vehicle, concept 3 (Fig. 14), would probably maintain a slight "nose-up" dynamic trim condition. Figure 15 shows the amphibious concept of a ¼-ton vehicle.

RELIABILITY AND MAINTAINABILITY

SUMMARY

Problem

To review the impact of reliability on the operational requirements and cost effectiveness of a proposed Qualitative Materiel Requirement for a new ¼-ton utility truck.

Facts

The "Proposed Qualitative Materiel Requirement for Truck, Utility, ¼-Ton (CDOG Par 1636e)" was written in compliance with AR 705-5, App I, "Format for Submitting Qualitative Materiel Requirements (RCS CSCRD-64)."

The analysis and evaluation was based on the existing levels of reliability and maintainability of the vehicle and on the research results of RAC Research Project 124, "Criteria for Limits of Reliability and Maintainability," for generic classes of Army equipment.

Appropriate ARs were examined to determine the objective of the QMR. The recommendations of this report are established to support these objectives.

Discussion

The determination of the impact on operational requirements and cost effectiveness of the reliability specified in the proposed QMR was performed in three parts. The first part of the investigation was to define reliability and analyze and evaluate the significance of the specifications. The second part was to analyze and evaluate RAC-collected and -correlated maintenance data to estimate the reliability experienced with the present ¼-ton utility truck, the M151. The third part was to analyze and evaluate the relative magnitude of the difference between the reliability specifications of the proposed QMR and the actual reliability of the M151 to determine the feasibility of the specification and the resultant impact on operational requirements and cost effectiveness.

Conclusions

1. The impact of reliability on the operational requirements and cost effectiveness cannot be statistically assessed because reliability data are not available; the combat-mission reliability of operational Army equipment cannot be confidently predicted at this time.

2. Analysis and evaluation of maintenance data to determine combat-mission reliability are of doubtful value because maintenance is not directly relatable to the reliability the equipment is capable of providing in combat.

3. RAC has determined that AR 705-5 does not require the QMR to contain a specification of reliability, as a probability, unless it is practical to do so.

4. RAC has determined that it is not practical to specify reliability as a probability in the QMR even if it could be determined. The specification of reliability would impose a predetermined, detailed, hardware concept on the QMR that would curtail imaginative and creative development of materiel to the maximum extent practical within the state of the art.

5. The level of reliability should be indicated in the QMR by the detailed specification of tactical operational parameters, i.e., a typical sustained battlefield operational capability, or an average life with normal servicing requirements in hours or miles. These characteristics are outlined in AR 705-5.

Recommendations

1. RAC recommends that the Army not specify reliability as a probability in the QMR. The proper specification of the parameters required by AR 705-5 will satisfactorily indicate the level of reliability required to accomplish the QMR objective. The proposed QMR for the $^1/_4$-ton utility truck should be rewritten to provide a clearer description of the tactical requirements of the vehicle. The typical combat mission should be expanded to include references to all the operational, environmental, and tactical factors that will affect the usefulness of the vehicle so that these factors can be included in the design characteristics and become a part of the trade-off considerations. The average life expectancy, with normal servicing (as specified in the operational and maintenance manual) of components, assemblies, and systems should be included in the QMR whenever technically realistic values can be derived that will contribute to the capability and reliability of the vehicle without limiting the optimization of design characteristics that must remain flexible to satisfy trade-off considerations.

2. RAC recommends that the Army reorient Army-sponsored reliability research programs. The emphasis should be changed from the statistical analysis of operational experience of a peacetime Army to a systems-engineering concept based on the technical analysis and evaluation keyed to missions and simulated combat conditions. It is only through such a program that the combat-mission reliability of Army materiel can be determined. Vital information can then be gathered to allow the future prediction of reliability as a probability.

SIGNIFICANCE OF THE SPECIFICATIONS

Introduction

The concepts of reliability and maintainability have been developed as an engineering science to satisfy the need for a more complete and detailed understanding of the effect of probability, time, and environment on performance requirements. The importance of these concepts has increased as a function of equipment complexity and the catastrophic effect of failure. This section

will define reliability and analyze and evaluate the significance of the proposed reliability specifications for the QMR.

Reliability Definition

Reliability is the probability that an equipment item will perform its purpose adequately for the period of time intended under the operating conditions encountered. It should be observed that the definition stresses four elements, viz., probability, adequate performance, time, and operating conditions.

Probability, the first element of the reliability definition, is a quantitative term because it is expressed in a numeric form, i.e., a fraction or a percentage that signifies the number of times an event can be expected to occur in a total number of trials.

Adequate performance, the second element, indicates that criteria must be established that clearly specify, describe, or define what is considered to be satisfactory operation for mission success.

The third element of the reliability definition, time, is one of the more important because it represents a measure of the period during which a certain degree of performance can be expected. Without knowledge of the probability that an equipment item will function or survive for a given time, there is no way of assessing the probability of completing a mission or task scheduled to last for a given period.

The operating conditions under which an equipment item is expected to function is the fourth element of the reliability definition. The factors establishing these conditions encompass more than the traditional environmental factors of temperature, humidity, shock, and vibration. The operating conditions are determined by the capability of operating and maintenance personnel, operating and maintenance procedures, operational suitability, maintainability, and auxiliary and supporting equipment, as well as operational environment.

The reliability expressed for an equipment item is generally accepted as a figure of merit that represents solely the confidence of success. Reliability cannot magically perform this function. When reliability is expressed as a percentage that does not contain a complete definition of adequate performance, time interval, and operating conditions it is a meaningless number that has no valid usefulness.

95 Percent Reliability

The proposed QMR specified in Sec II, Par 2.b that the vehicle must be capable of operating in all seasonal conditions with a mission reliability of 95 percent with only driver maintenance, and in subarctic and tropical climates with a mission reliability of 95 percent with the use of modification kits. This mission is defined as operations in a combat zone for 6 days with an average utilization (40 percent of which is idling, 40 percent cross-country, and 20 percent over secondary roads) of 75 miles/day at safe operating speeds.

When the mission duration is a relatively short part of the life of the system the exponential failure law may satisfactorily compute the reliability number obtained under the conditions of a constant failure rate. When the mission duration approaches the life of the system the exponential failure law is only approximate and should be used only for illustrations in the relative effect of parameter variations.

The equation can be expressed as

$$R_{MD} = e^{-MD/MTBF} \tag{1}$$

where R_{MD} = probability of survival or reliability for a certain mission duration
e = base of natural logarithms
MD = mission duration
$MTBF$ = mean time between failure

The mission duration MD is specified as 450 miles; the reliability is 95 percent. These values are substituted in Eq 1

$$0.95 = e^{-450/MTBF} \tag{2}$$

and the equation is solved for MTBF.

$$MTBF = -450/\ln 0.95 = 8750 \text{ miles} \tag{3}$$

This indicates that the vehicle must be capable of negotiating an average of 8750 miles without encountering a failure that would immobilize the vehicle and abort the mission. An analysis of operational data has revealed that the M151 has seven systems that constitute a reliability problem (refer to Table 17).

The product rule of reliability is applicable when a number of components of a system are connected so the failure of any one component causes a failure of the equipment; these components are then considered to be functionally in series. In terms of survival this means that each component must survive if the equipment is to survive. The equipment can be no better than the component with the lowest probability of survival or reliability. When these series components are independent the equipment satisfies the requirements of the multiplication law. Equipment reliability can be found by multiplying the individual reliability of the components together.

The mathematical equation for the product rule is

$$R_{MD_e} = \left(R_{MD_1}\right)\left(R_{MD_2}\right)\left(R_{MD_3}\right)\cdots\left(R_{MD_n}\right) \tag{4}$$

which states that the probability of satisfactorily completing the mission with only driver maintenance is equal to the product of the individual values of reliability for each of the n components.

When the equipment reliability is specified and component reliabilities are not known the average reliability of n components can be determined by taking the nth root of the equipment reliability.

$$R_{MD_n} = \sqrt[n]{R_{MD_e}} \tag{5}$$

The seven systems that constitute a reliability problem in the M151 are functionally in series. Using these values for illustration in Eq 5 gives

$$R_{450_7} = \sqrt[7]{0.95} \tag{6}$$

The average reliability of each of these component systems must be 99.3 percent. This will indicate a required mean time between failure for each system, using Eq 1, of

$$\text{MTBF} = -450/\ln 0.993 = 62{,}000 \text{ miles} \tag{7}$$

The mean time between failure for each system must then be 62,000 miles.

The power-plant system contains two components, the engine and the transmission. The average mean time between failure for each component can also be computed using the product rule, Eq 5

$$R_{450_2} = \sqrt[2]{0.993} \tag{8}$$

The average reliability of each of these components must be 99.63 percent. This will indicate a required mean time between failure for each system using Eq 1, of

$$\text{MTBF} = -450/\ln 0.9963 = 123{,}000 \text{ miles} \tag{9}$$

The mean time between failure for both the engine and the transmission must be 123,000 miles.

Because of the reliability characteristic described by the product rule the components experiencing a low mean life must be determined and technologically improved if the reliability of the system is to be improved. To ustrate this significance of the product rule, if one of the seven systems is restricted to a mean life of 25,000 miles the average mean life of the remaining six systems must increase to approximately 78,000 miles. If two of the seven systems are restricted to a mean life of 25,000 miles, the average mean life of the remaining five systems must increase to approximately 151,000 miles.

90 Percent Probability

The proposed QMR specifies in Sec IV, Par 7.a (14) that it is essential for the vehicle to possess a 90 percent probability of being operated for 15,000 miles with only scheduled organizational maintenance, without failure of either accessories or integral major components, and for 25,000 miles without the need for major overhaul or the replacement of a major component.

This specification overlaps the 95 percent reliability specification and results in two different values of the required mean life of the components.

The significance of this specification can be illustrated by substitution into Eq 1. For a 90 percent probability of satisfactorily operating 15,000 miles

$$\text{MTBF} = -15{,}000/\ln 0.90 \tag{10}$$

which is approximately 142,000 miles. For a 90 percent probability of satisfactorily operating 25,000 miles

$$\text{MTBF} = -25{,}000/\ln 0.90 \tag{11}$$

which is approximately 237,000 miles.

The values computed using the assumptions of the exponential law are gross approximations when used to estimate the mean life of the system. However, they do illustrate the order of magnitude of the incompatibility that sep-

arates the mission reliability and 90 percent probability specification. The conditions that constitute satisfactory operation are also several orders of magnitude higher for this specification than for the 450-mile mission.

The significance of the proposed QMR is summarized in Table 34.

TABLE 34

Reliability Specifications for the Proposed QMR for ¼-ton Utility Truck

Specified reliability (probability of survival), %	Specified time interval (mission duration), miles	Required failure-free life (mean time between failure), miles		
		Mode A[a]	Mode B[b]	Mode C[c]
95	450	< 8,750	8,750	> 8,750, but <142,000
90	15,000	142,000	>142,000, but <237,000	>142,000, but <237,000
90	25,000	>142,000, but <237,000	>142,000, but <237,000	237,000

[a]Scheduled organizational maintenance only.
[b]No immobilizing failures.
[c]No major overhaul or replacement of a major component.

ANALYSIS OF MAINTENANCE DATA

Introduction

The performance of equipment for other than laboratory conditions cannot be specified completely in absolute terms because of the limitation in present knowledge, and the apparent magnitude of the effect of environment. Therefore the level of performance can be specified only as a probability of success in an environment that can be only partly defined and for a period of time when the level of performance is degenerating.

This section will analyze and evaluate RAC-collected and -correlated maintenance data to estimate the reliability experienced with the present M151 ¼-ton utility truck.

Data Source

RAC has the largest and most extensive maintenance data records for several particular US Army vehicles in existence. The collection and correlation of these data extend beyond the original issue date for the lastest series of vehicles. A complete maintenance history to date is available for a sample of the M151 ¼-ton utility truck issued to the Seventh Army. The 100 vehicles that compose the sample used in this study were issued in the fall of 1961 to two armored and two mechanized infantry battalions. The average odometer reading is 17,300 miles, and the range of the odometer readings is from 12,500 miles to approximately 24,000 miles. The data were obtained from basic transaction records in the field by RAC personnel. The environmental conditions are those of active operational training on the European land mass while maintaining a state of advanced readiness.

Failure Prediction

The maintenance history of the sample was analyzed and evaluated to determine the relative level of reliability that was indicated by the replacement of components that would immobilize or otherwise incapacitate the vehicle. The replacement of these components was assumed to be indicative of failure or pending failure.

ERRATA

For: Table 35, p 84.
Replace with new table:

TABLE 35

Component Replacements Indicative of Failure for M151 ¼-ton Utility Truck

(Sample size, 100 vehicles; average age, 17,000 miles)

Component	Quantity	
	Subtotal	Total
Power plant		42
Engine	12	
Transmission *	30	
Power train		80
Clutch *	43	
Differential	5	
Wheel bearing	24	
Propeller shaft	2	
Universal joint	6	
Cooling system		61
Radiator *	29	
Hose	12	
Pump	3	
Fan belt	17	
Fuel system		51
Fuel pump	17	
Carburetor *	34	
Ignition system		40
Distributor *	35	
Coil	5	
Electrical system		83
Battery	15	
Generator	16	
Regulator *	52	
Brakes		3
Master cylinder	3	
Total	360	360

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The component replacements indicative of failure are shown in Table 35. The components have been divided into seven systems. The failure of any one of the 19 components within the seven systems shown in this table would immobilize or incapacitate the vehicle, resulting in an aborted mission. The

replacements were fairly evenly spread among the systems; however, six of the components accounted for 223 of the 360 replacements experienced by the sample during the history interval. These six components are identified by an asterisk in Table 35. It can be concluded that the six components that contribute significantly to the unreliability of the vehicle should be improved if the reliability of the vehicle is to be increased.

Mission-Reliability Prediction

Mission reliability is defined as the probability that the equipment will give specified performance for the duration of a mission when used in the manner and for the purpose intended, provided the equipment is functioning properly at the start of the mission.

The estimate of the mission reliability of the M151 is based on the mean time between replacement of the components of the system rather than the mean time between replacement of individual components. The mean time between replacement of the individual components is not a significant number for the 13 less frequently replaced individual components and only becomes significant when these components are treated as part of the overall system.

The distribution of the time between replacement experienced by the sample vehicles is shown in Fig. 16. The cumulative replacement distribution can

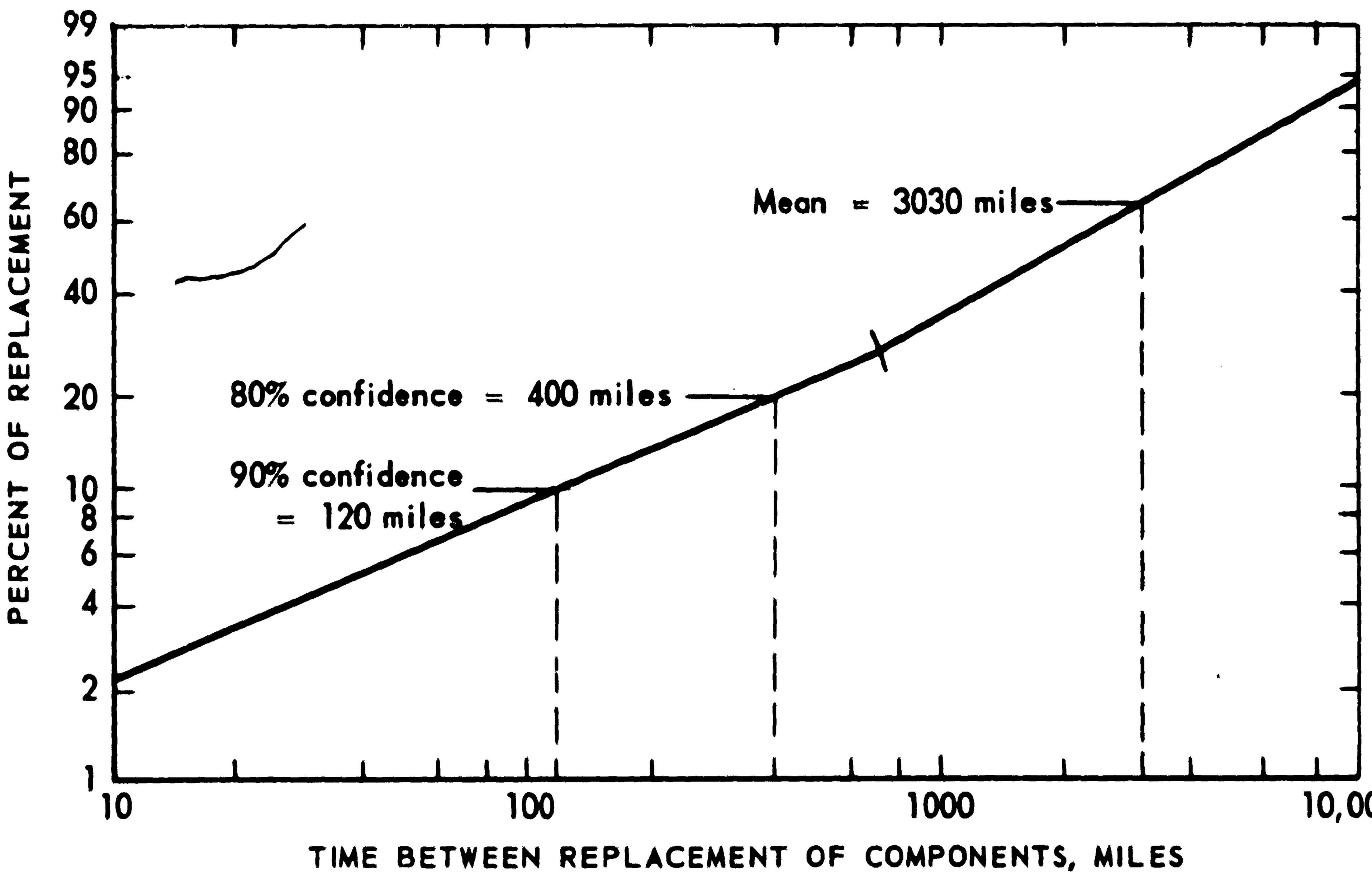

Fig. 16—Mean Time between Replacement of Components of the M151 ¼-ton Utility Truck

Sample size, 100 vehicles; average age, 17,300 miles; standard deviation, 3240 miles; β, 0.83

be closely approximated by the Weibull Distribution, and the data have been plotted on Weibull graph paper. The mean time between replacement was computed to be 3030 miles. The standard deviation is 3240 miles, indicating that the time between replacement has a very large variation. When this value is substituted into Eq 1

$$R_{450} = e^{-450/3030} = 0.86 \tag{12}$$

The average reliability of these sample vehicles for a 450-mile mission under the environmental conditions encountered by the Seventh Army is 86 percent.

Mission-Reliability Degradation

The reliability of 86 percent is a statistical average over the portion of the expected life the vehicles have consumed to date. As the vehicle wears out it becomes less reliable. The data for the M151 were analyzed by intervals to determine the characteristics of this degradation. The mission-reliability degradation as a function of vehicle age is shown in Fig. 17. The portions of the curves that were computed are shown as solid lines, and the estimated or predicted portions are shown as dashed lines. The mission-reliability experiences degradation from issue from about 97 percent to about 74 percent at the average age of 17,300 miles. The analysis indicated that the degradation rate was decreasing, and a projection of the curve based on the reduced sample after 17,300 miles indicated that an asymptotic limit could be established at 71 percent. This indicates that the average mission reliability of the M151 would be 71 percent or greater during the useful life of the vehicle. The time between replacement of components for 71 percent reliability will be 1312 miles.

Corrective Maintenance

The corrective-maintenance reliability degradation as a function of vehicle age is shown in Fig. 18. Corrective maintenance is defined as the maintenance performed to restore an item to a satisfactory condition by correcting a malfunction that has caused degradation of the item below the specified performance. The repair and replacement of components was used to estimate this maintenance requirement. The curves have the same general shape as those developed for the mission-reliability data. The statistical average was computed as 69 percent. The corrective-maintenance reliability decreases from approximately 94 percent at issue to approximately 46 percent at the average age. The asymptotic limit was established at 43.5 percent. This indicates that the average corrective-maintenance reliability of the M151 would be 43.5 percent or greater during the useful life of the vehicle. The time between corrective maintenance for 43.5 percent reliability will be 542 miles.

Confidence Factors

The average reliability is the reliability that will most likely occur and is commonly associated with a confidence or probability of 50 percent. Half of the experienced reliabilities will be larger than the average, and half will be smaller. The distribution of the times between replacement determine the variation that can be expected to occur in the experienced reliability. Refer to Fig. 16. Because the distribution is skewed to the lower values the lower values occur more frequently than the higher values; the mean occurs at 68 percent instead of 50 percent. The median or 50 percent value of 1800 miles, which is the true 50 percent confidence value, results in a reliability of

$$R_{450} = e^{-450/1800} = 0.78 \qquad (13)$$

or 78 percent. This value is less than the average or most likely reliability.

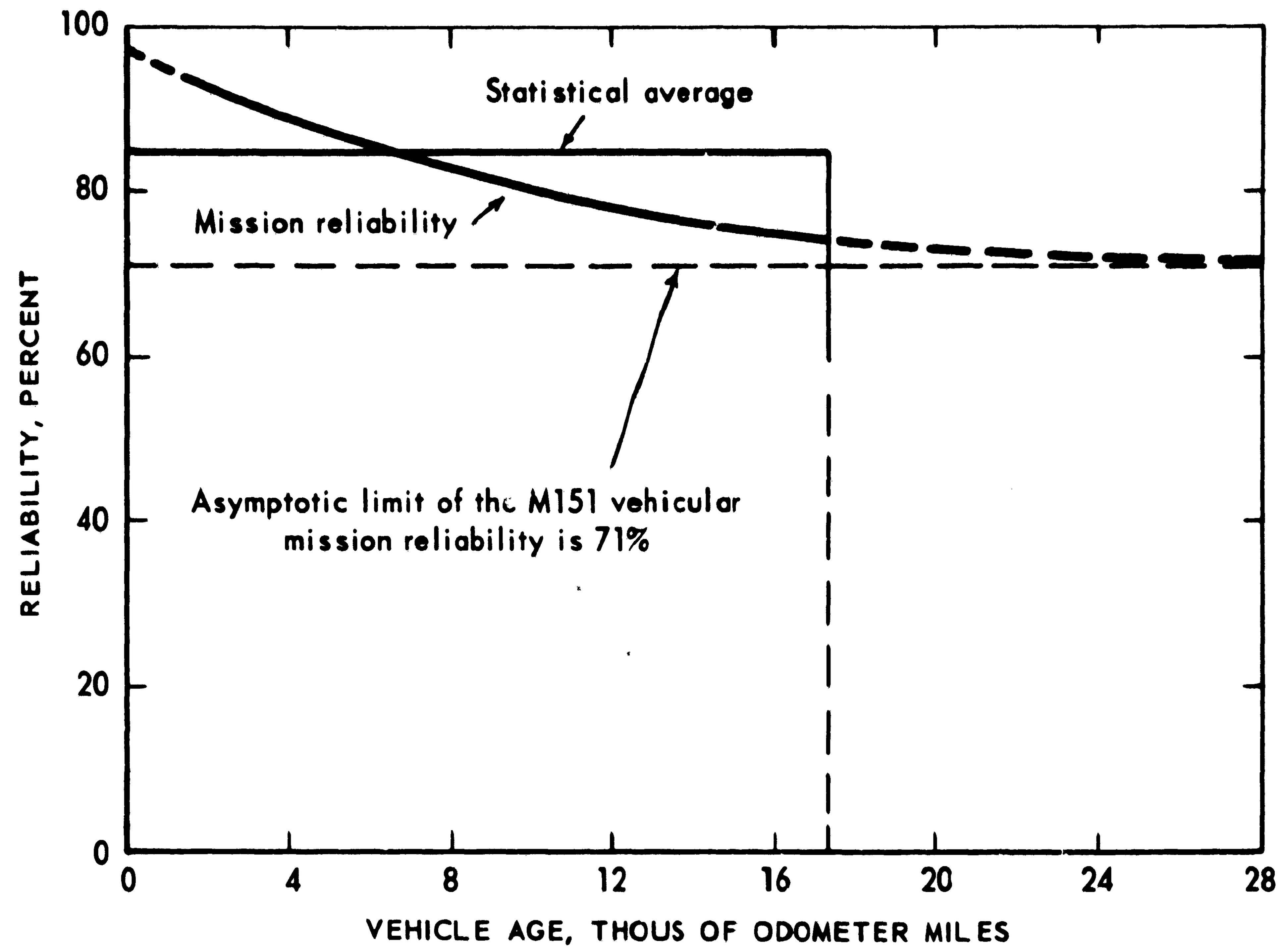

Fig. 17—Mission Reliability Degradation as a Function of Vehicle Age

Sample size, 100 vehicles; average age, 17,300 miles;
mission distance, 450 miles

——— Statistical computation — — — Prediction

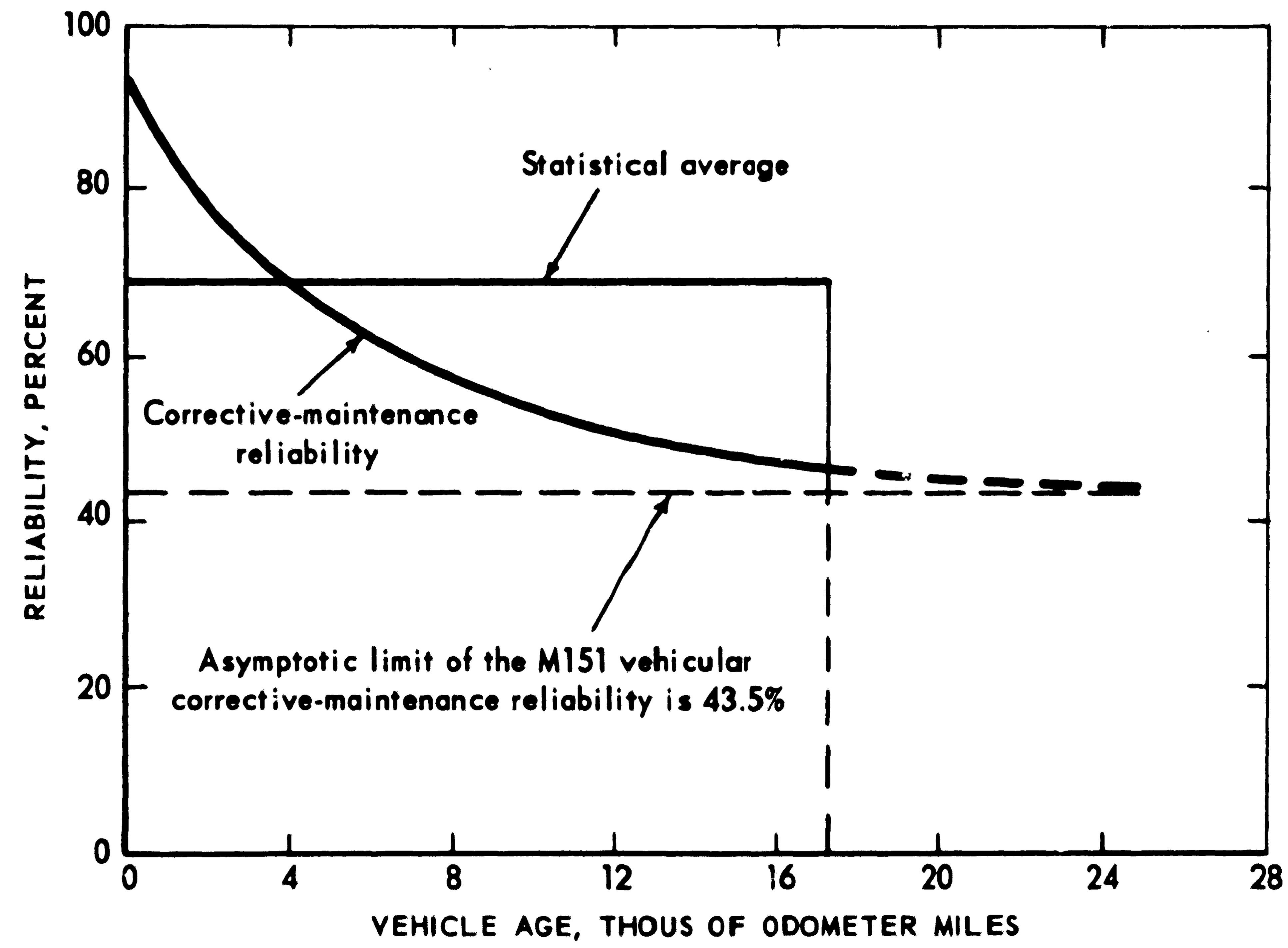

Fig. 18—Corrective-Maintenance Reliability Degradation as a Function of Vehicle Age

Sample size, 100 vehicles; average age, 17,300 miles;
mission distance, 450 miles

——— Statistical computation — — — Prediction

Notice that 20 percent of the experienced times between replacements are less than 400 miles. This reliability of

$$R_{450} = e^{-450/400} = 0.33 \quad (14)$$

or 33 percent, can be stated with an 80 percent confidence. Ten percent of the values are below 120 miles.

A reliability of

$$R_{450} = e^{-450/120} = 0.02$$

or 2 percent, can be stated with a 90 percent confidence. This is the value of confidence that is used most frequently.

TABLE 36

Probability of Survival for 12,500 Miles for the M151 ¼-ton Utility Truck

(Sample size, 100 vehicles)

System and component	Quantity of failures	Probability of survival, %	
		Component	System
Power plant			79
Engine	6	94	
Transmission	16	84	
Power train			39
Clutch	57	43	
Differential	5	97.5	
Propeller shaft	—	—	
Universal joint	1	99.9	
Wheel bearing	54	93.3	
Cooling system			68
Radiator	24	76	
Hose	2	99	
Pump	3	97	
Fan belt	13	93.5	
Fuel system			68
Fuel pump	6	94	
Carburetor	20	80	
Air-hose intake	10	90	
Ignition system			78
Distributor	22	78	
Coil	3	97	
Electrical system			53
Battery	7	96.5	
Generator	14	86	
Regulator	36	64	
Brake system			99
Master cylinder	1	99	
Overall			5.8

This large variation in the distribution of time between replacements has occurred for all the ground vehicles studied by RAC. The prediction of mission reliability of this vehicle is of doubtful value if the mission operating conditions vary considerably from the operational conditions of Seventh Army between 1961 and 1963.

The fact that the Army is maintaining a state of readiness will have an effect on the replacement rate. The degree of this effect cannot be determined from the data. Therefore the variation, or error, in using the replacement of a component to imply a failure rate cannot be quantitatively assessed. This single assumption could have a large effect on the distribution of the parameters and will be discussed in more detail in the next section, "Evaluation of the Operational Concept."

Probability of Survival

The probability of survival for 12,500 miles for the M151 $\frac{1}{4}$-ton utility truck is shown in Table 36, which contains a list of all the critical components that failed during the first 12,500 miles of operation within the 100-vehicle sample. The probability of survival was computed for each component. These probabilities were multiplied to obtain the probability of survival for each of the major systems. The overall vehicle probability of 5.8 percent was computed by multiplying the major systems probabilities.

This computation indicates that there is a 5.8 percent probability that the M151 operating under the environmental conditions experienced by the Seventh Army would be capable of going the first 12,500 miles of its life with only scheduled organizational maintenance. This estimate is based on the assumption that all corrective maintenance to components could wait until the next scheduled maintenance period without immobilizing the vehicle.

EVALUATION OF THE OPERATIONAL CONCEPT

Introduction

The primary advantage of accumulating reliability data is that these can be used to predict or calculate the reliability of an equipment item when it is operated under the conditions that the data represent. The reliability technique, at best, produces a broad estimate of the expected reliability.

The ultimate measure of reliability is theoretically in the field, where the equipment is subjected to the actual conditions of use and operation for which it was designed.

This section will analyze and evaluate the relative magnitude of the difference between the reliability specified in the proposed QMR and the reliability experienced by the M151 to determine the feasibility of the specification and the resultant impact on operational requirements and cost effectiveness.

Reliability and the QMR

The specification of reliability and maintainability parameters must be compatible with the objectives in Army regulations.

The responsibilities and the establishment of policies and procedures for conducting research and development of materiel in the DA are specified in AR 705-5, 14 Jan 63, pertinent sections of which are quoted here.

The sentence numbers were inserted by the author of this section.

[1] Department of the Army requirements for new equipment or for major innovations or improvements related to research and development as developed from new concepts, are normally expressed as qualitative materiel requirements or small development

requirements. [2] Significant Army materiel needs are stated as qualitative materiel requirements (QMR). [3] A qualitative materiel requirement (RCS CSCRD-64) is a Department of the Army approved statement of a military need for a new item, system, or assemblage, the development of which is believed feasible. [4] The qualitative materiel requirement is directed toward attainment of new or substantially improved materiel which will advance the Army's major materiel needs in terms of military characteristics and priorities and relates materiel to the operational and organizational context in which it will be used. [5] QMR's are stated at the earliest time after the need is recognized and feasibility of development has been determined. [6] The small development requirement (SDR) (RCS CSCRD-65) states a Department of the Army need for the development of equipment of proved feasibility which can be developed in a short time and because of low cost and simplicity of development does not warrant the establishment of a qualitative materiel requirement. [7] Technical characteristics amplify the characteristics contained in the qualitative materiel requirements. [8] Normally amplification is based on technical feasibility studies and component development conducted in response to a qualitative materiel development objective. [9] They provide the basis of specifications for the developer and assure development of a militarily acceptable item at a predictable cost. [10] They will reflect adequate consideration of the specific environment in which the end item will operate to assure that only those specifications or parts of specifications directly applicable to anticipate environments eventually result in contractual requirements. [11] They will include a quantitative reliability and maintainability objective that can be achieved within acceptable time and cost limits.

The "Format for Submitting Qualitative Materiel Requirements" is described in App I, pertinent sections of which follow.

[12] Characteristics stated will represent mandatory or minimum acceptable performance features that are "essential" to product's acceptance; and features that are "desirable," i.e., desired if achievable without a disproportionate increase in cost, complexity, and lead time while maintaining the required standards of reliability and maintainability.

[13] Performance Characteristics—specific performance requirements to permit clear understanding of features that are "essential" to product's acceptance; and features that are "desirable," i.e., desired if achievable without a disproportionate increase in cost, complexity, and lead time while maintaining the required standards of reliability and maintainability. [14] Performance characteristics provide sufficient guidance to form the basis for technical characteristics and preliminary engineer design and influence the development of materiel more than any other portion of the qualitative materiel requirement. [15] Include considerations, as applicable, of reliability criteria to indicate that the item will perform its mission adequately for the period intended and under the expected operating conditions. [16] To the extent practical, express quantitatively (if available, use probabilities).

The primary purpose of the QMR is directed toward attainment of new or substantially improved materiel. A secondary purpose of the QMR is implied, viz., that it will supply planning information to operational and supporting activities whereby they can evaluate the impact of the materiel specification on their activities. Refer to sentences 1, 2, 3, and 4 of the quoted section. The AR 705-5 text does not state that the QMR will specify reliability or maintainability quantitatively.

The format for submitting a QMR, App I of the AR, as quoted in sentences 12 and 13 does refer to "the required standards of reliability and maintainability." This is clarified in sentence 15 where it is stated, "include considerations, as applicable, of reliability criteria to indicate that the item will perform its mission adequately for the period intended and under the expected operating conditions." Sentence 16 further clarifies the reliability specification requirement

for a QMR by stating, "To the extent practical, express quantitatively (if available, use probabilities)."

The specification of quantitative reliability parameters in the QMR is therefore not required by AR 705-5 unless it is practicable to do so.

The "Reliability Program for Materiel and Equipment" as stated in AR 705-25 implies that the quantitative specification of reliability is practicable and that many operational and planning parameters can be determined and specified quantitatively at the QMR level. The rationale of this concept expressed in AR 705-25 will not be reviewed within the confines of this study. However, several related questions will be discussed in detail.

There is a basic difference between the QMR and the Technical Characteristics, a subordinant specification. The QMR is a general document stating a general hardware concept that will satisfy an Army tactical concept. The Technical Characteristics is still a general document, but it has been related to a specific hardware concept based on technical feasibility and component development. This relation is specified in sentences 7 and 8 in the quoted section. Sentences 9, 10, and 11 state the purpose of the Technical Characteristics and what they should contain relative to reliability.

Reliability must be related to a specific hardware capability or it has no meaning. In most instances reliability is subordinant and dependent on the required performance. In all instances it must be a trade-off factor relative to performance and cost. This trade-off cannot be performed or even assessed until a specific hardware concept has been determined. Even when the Army tactical materiel requirement has been developed to the Technical Characteristics stage, it is difficult to assess or predict reliability because of an inability to obtain relative empirical data.

Reliability Data

The inherent reliability of an equipment item is predictable within certain confidence levels when this prediction is based on data obtained from previous experience. This implies that data used for reliability prediction should be collected from supervised sources. Therefore the methods, procedures, and environmental conditions applicable to these data should be clearly specified in order to assure objective information.

Operational reliability is a combination of the inherent reliability of the equipment, which is degraded as a function of the usage it receives. It is associated with those parameters that are not an inherent part of the equipment but whose effects are very important in the overall assessment of the reliability of the system. The factors that constitute operational reliability are difficult to evaluate because they are intangibles that cannot be expressed quantitatively. They include the capability of the operator, the maintenance personnel and procedures, the operating conditions, and evaluation of what is considered satisfactory operation.

Worthwhile reliability data can be obtained only as a result of human effort. The proper and useful recording of information is the culmination of attention to diagnosis, test, inspection, analysis, and repair or replacement. Maintenance and/or operating personnel should be able to differentiate the various types of failures and to determine the true cause of t ouble. They should not confuse

failures of a primary nature with failures of a secondary nature. The ability to discriminate between causes of failure is a most important capability of operating personnel.

The analysis and evaluation of maintenance data to determine combat mission reliability are of doubtful value. If the maintenance data are complete and contain no omissions, they may represent the worst case. However, even this assumption cannot be logically supported because of considerable difference in operating conditions.

The peacetime mission of the ¼-ton utility truck is very different from the wartime combat mission it will be expected to perform. The peacetime mission is primarily to be available to assure combat readiness. For a combination of reasons, peacetime experience is an indirect, incomplete, and clouded indicator of wartime requirements.

Maintenance of Army equipment is a major problem. However, effective maintenance of Army equipment, although crucial to the mobility and readiness of Army forces, is not directly relatable to the reliability the equipment is capable of providing in a combat situation.

An analogy of the relation between the indicated peacetime mission reliability and the wartime combat mission reliability can be made to a smoke screen analysis. Can a detailed measurement of the size, growth rate, velocity, etc., of the smoke screen by lay personnel ever indicate with confidence the size, growth rate, velocity, etc., of the fire? The fact that the cause of the smoke screen is a smudge pot or a California brush fire may not be evident without a close, detailed, accurate investigation. Perhaps the subjective opinion of an expert based on extensive knowledge and experience could supply predictions with far greater confidence.

The maintenance data utilized in the previous section "Analysis of Maintenance Data" are representative of what is being experienced by those particular sample vehicles. Field modifications and Army policies, procedures, and operational concepts have changed during and since the time the data were recorded. The effect of these changes cannot be quantitatively assessed at this time. It is doubtful if these data can predict the actual daily mission reliability with any known confidence.

Therefore the reliability of the M151 cannot be assessed by merely processing the data as if they were reliability data. The relative magnitude of the difference between the reliability specified in the proposed QMR and the reliability being experienced by the M151 cannot be assessed.

An Effective Measure of Reliability

The peacetime Army has an objective—combat readiness. If war begins, combat readiness must produce maximum effectiveness in combat. Therefore the primary objective with respect to materiel is maximum effectiveness in combat; maximum combat readiness may be considered the secondary objective.

The primary objective of a materiel requirement specification must be directed toward obtaining the desired level of combat effectiveness. Reliability is the probability of an equipment item performing its purpose adequately for the period of time intended under the operating conditions encountered. The primary reliability concern is combat mission reliability. The four elements of the reliability definition must be for the combat situation.

The operational concept of reliability measurement and prediction is theoretically based on data from field utilization of the equipment subjected to the actual conditions of use and operation for which it is designed. The utilization of maintenance data to derive mission reliability characteristics can only be applicable under conditions that the data represent, which are those of the peacetime Army. The equipment was not primarily designed for the peacetime Army.

RAC proposes that the only effective measure of reliability for Army equipment must be in combat or in a simulated combat situation. A simulated combat situation whereby the mission reliability of the M151 $^1/_4$-ton utility truck could be determined is as follows: Select at random from combat-ready units appropriately sized samples of vehicles. Perform a preliminary inspection sufficient to verify the vehicles' condition and readiness, but not detailed enough to disturb the existing condition of the vehicle. Operate the vehicles according to a properly designed test program such as the mission proposed in the QMR in Sec II, Par 2.b. There is a possibility that such a program could be operated consecutively with other training exercises. When a vehicle fails, a detailed technical analysis and evaluation would be performed to determine the cause of the failure, and other contributing environmental factors. The experience of the sample vehicles would be supplemented by the analysis of appropriate data such as the Army equipment-record-system data. The percentage of vehicles that could complete the test satisfactorily would represent the mission reliability. The test would be analogous to the first 6 days at the outbreak of war. The analysis and evaluation of the results of such a test could determine existing reliability and provide a firm base for design improvement of present and future vehicles. This proposed program will provide reliability data keyed to <u>missions</u> and <u>simulated combat conditions</u>.

COST ANALYSIS

TARGET COST

Various means were used to obtain component and vehicle costs on the proposed $\frac{1}{4}$-ton utility truck. During this study it was difficult to obtain firm costs on vehicle components from vendors or truck manufacturers since they consider these costs proprietary in nature. It was also generally agreed that many factors that can vary the cost structure must be considered. Some of these factors are the delivery rate, quantities required, production capacity at the time, available tooling, and management philosophy at the time they apply, the burden, rate, etc. The present M151 $\frac{1}{4}$-ton truck is being purchased for $2442 average unit cost. One of the desirable objectives of the present QMR is to produce a $\frac{1}{4}$-ton truck for a target cost of $1900. This study has determined that an austere $\frac{1}{4}$-ton truck can be produced for approximately $1900, but at the expense of some desirable features and with a reduction in reliability. This estimated cost was based on simplifying or modifying the vehicle with many commercially available components, totaling a cost reduction on which to base the estimated target cost.

Incorporation of the commercial items affects the vehicle's reliability but takes advantage of lower-priced alternative high-production commercial items. Another approach would be to modify a present commercially available vehicle, e.g., the Kaiser Corporation's Jeep or the International Harvester Scout. These vehicles have good performance characteristics and do satisfy most commercial users' requirements. These vehicles, although not nearly so rugged as the present M151, are acceptable to the user as an effective vehicle for the cost. These vehicles may be modified to incorporate a 24-v electrical system—commercially radio suppressed—in lieu of the present 12-v system, more rugged 6-ply tires, and many other modifications and still be within the $1900 target cost. The reliability of this vehicle, however, would not meet the QMR.

The austere vehicle would not have floating or swimming capabilities, since this requirement would substantially increase the cost.

In summary, this study group has concluded that it is possible to provide an austere $\frac{1}{4}$-ton utility truck, but at the expense of reliability, floatability, and, to a degree, other desirable features.

TABLE 37

Estimated Component Cost

Component	Estimated cost of M151 parts, dollars	Cost decrease resulting from substituting commercially available parts, dollars
Radiator	16.70	—
Carburetor	15.50	11.30
Air cleaner	9.74	—
Fuel pump	16.00	16.00
Fuel tank	13.50	—
Muffler	4.26	1.00
Exhaust pipes	1.83	—
Spark plugs	1.80	—
Igniter	16.70	—
Starting motor	21.00	11.00
Generator	58.70	34.00
Regulator	20.40	20.40
Batteries	15.80	7.90
Headlights	9.50	—
Transmission and transfer	230.00	105.00
Propeller shaft	28.00	—
Differentials	250.00	130.00
Sleeve assembly	23.10	—
Shaft and cross assembly	22.60	—
Flanges	20.80	—
Arm and shaft assembly	38.40	—
Rear supports	13.20	—
Arm and seat assembly	56.10	—
Cross-member assembly	66.00	—
Support assembly	28.30	—
Steering linkage	10.50	—
Steering gear	14.30	—
Brake drums	10.10	—
Brake assembly	15.90	3.20
Wheels Tires	92.50 62.00	23.00
Instruments	15.90	4.66
Engine	248.00	5.00

Component	Estimated cost of M151 parts, dollars	Cost decrease resulting from substituting commercially available parts, dollars
Body	132.00	35.00
Windshield	23.40	—
Rear-seat assembly	22.60	22.60
Trim assembly	12.90	—
Front-seat assembly	49.50	6.00
Hood assembly	10.20	—
24-v switch	8.51	8.51
Spindle assembly	42.60	—
Towing eyes	6.74	6.74
Circuit breaker	5.57	5.57
Wiring harness	34.52	4.52
Horn	7.20	4.20
Ignition, starter switch	18.00	7.00
Air-drop eyes and nuts	7.84	7.84
Door and curtain assemblies	40.56	40.56
Right windshield wiper	3.80	3.80
Miscellaneous	4.27	4.27
Wheel nuts and studs	6.00	3.00
Oil-pressure switch	2.49	2.49
Right air vent	2.36	2.36
Floor drains	0.80	0.80
Undercoat	10.00	10.00
Rubber, military specification	30.00	15.00
Hose clamps	3.77	1.77
Rear-view mirror	7.50	1.50
Fuel-tank cap	0.98	0.48
Radiator cap	0.67	0.27
Total cost reduction		566.74

VEHICLE COST REDUCTION

The present M151 was studied by systems or by individual components to determine possible cost reduction and still retain substantially present performance and capabilities. The cost estimates listed in Tables 37 and 38 were obtained from component manufacturers presently supplying military or commercial items, and from present spare-parts cost data available to the government.

TABLE 38

Electrical-System Cost Reduction[a]

Item	Comment	Estimated cost reduction, dollars
Ignition system	No significant change	—
Starter	No significant change unless alternative engine is used, then cost savings would be	11.00
Lighting system	No significant change	—
Batteries	No significant change	—
Fuel system	Elimination of electric fuel pump, oil-pressure switch, circuit breaker, and associated cabling and connectors	20.60
Cabling	No significant change	—
Circuit breakers	Use of weatherproof circuit breakers instead of waterproof circuit breakers	1.20
Generator and regulator	Replacement of the present 25-amp generator and regulator with a 35-amp alternator and self-contained rectifiers and regulator	49.10
Total saving		81.90

[a]Possible cost reduction (in addition to that of Table 37) of electrical system by substituting commercial components where possible but retaining radio suppression and 24-v system.

EFFECT ON COST OF LARGER QUANTITY BUY

In this subsection the effect that a procurement of a larger quantity of vehicles than that planned for the Army might have on initial cost is discussed.

The planned $^1/_4$-ton truck buy for the Army is 10,000 vehicles/year for 3 years, a total of 30,000 vehicles. Other departments of DOD—AF, Navy, Marines—as well as other agencies of the US government will also require these vehicles. In addition to the US requirements, foreign governments maintaining military establishments are potential customers.

Assuming that an additional 15,000 vehicles are required, the estimates in Tables 39 and 40 indicate the effects a larger buy might have. Contacts with truck manufacturers in industry have indicated that the unit cost savings would be relatively small for an additional 50 percent increase in quantity to 45,000 units. However, the savings that would be realized by an increase from 30,000 to 45,000 units are shown in Table 39,which indicates that an estimated 9 percent reduction of unit cost per vehicle can be realized.

Tooling. The cost savings in tooling are estimated on the basis of amortizing the total cost over the number of units produced. Since the total quantities under consideration are relatively small (compared to the daily output of automobiles), the advantage of automating production cannot be realized. Automated production generally is not considered for quantities less than approximately 250,000 units.

TABLE 39

Savings Realized from a 50 Percent Increase in Quantity

Item	Manufacturing breakdown for	
	30,000 units, %	45,000 units, %
Tooling	2.0	1.5
Materials	55.0	52.5
Direct labor	13.0	12.0
Overhead or burden	15.0	12.0
General administrative	10.0	8.0
Profit	5.0	5.0
Total	100.0	91.0
Saving		9.0
		100.0

TABLE 40

Cost Decrease for Various Unit Increases

Item	Units					
	20,000	30,000	45,000	60,000	75,000	90,000
	Cost decrease, dollars					
Tooling	60.00	48.84	40.25	34.60	30.90	28.20
Materials	1405.00	1343.10	1287.00	1263.00	1238.00	1227.00
Direct labor	342.50	317.46	293.50	281.50	269.00	269.00
Overhead or burden	443.00	366.30	300.00	259.00	232.00	214.00
General and administrative	293.50	244.20	195.75	167.50	129.50	98.00
Profit	122.10	122.10	122.10	122.10	122.10	122.10
Total	2666.10	2442.00	2238.60	2127.70	2021.50	1958.30

Material. Most of the savings lie in the increased number of component parts that are peculiar to the $\frac{1}{4}$-ton truck. Other components that may have application to high-production commercial vehicles will contribute little if any cost savings as a result of the relatively small increase of 15,000 units (when compared to a commercial production of 1,000,000 parts).

Labor. The cost of direct labor is proportional to the total number of units purchased. The cost saving indicated here is primarily the result of

amortizing the learning costs over a larger quantity of vehicles after the labor cost has become relatively stabilized. This assumes of course that continuity of the program is maintained.

Overhead. Some overhead and burden cost savings are realized by the increase in quantities, since personnel and fixed costs are not significantly affected by the increase in numbers of vehicles to be produced.

General and Administrative. The general and administrative cost percentage generally varies inversely with the total volume of business, in this case resulting in a slight decrease in cost.

Profit. The percentage of profit does not vary significantly with volume. However, increased quantities may provide additional incentive to management to be more competitive in their bidding.

The decrease in costs when larger numbers are procured is shown in Table 40 and Fig. 19.

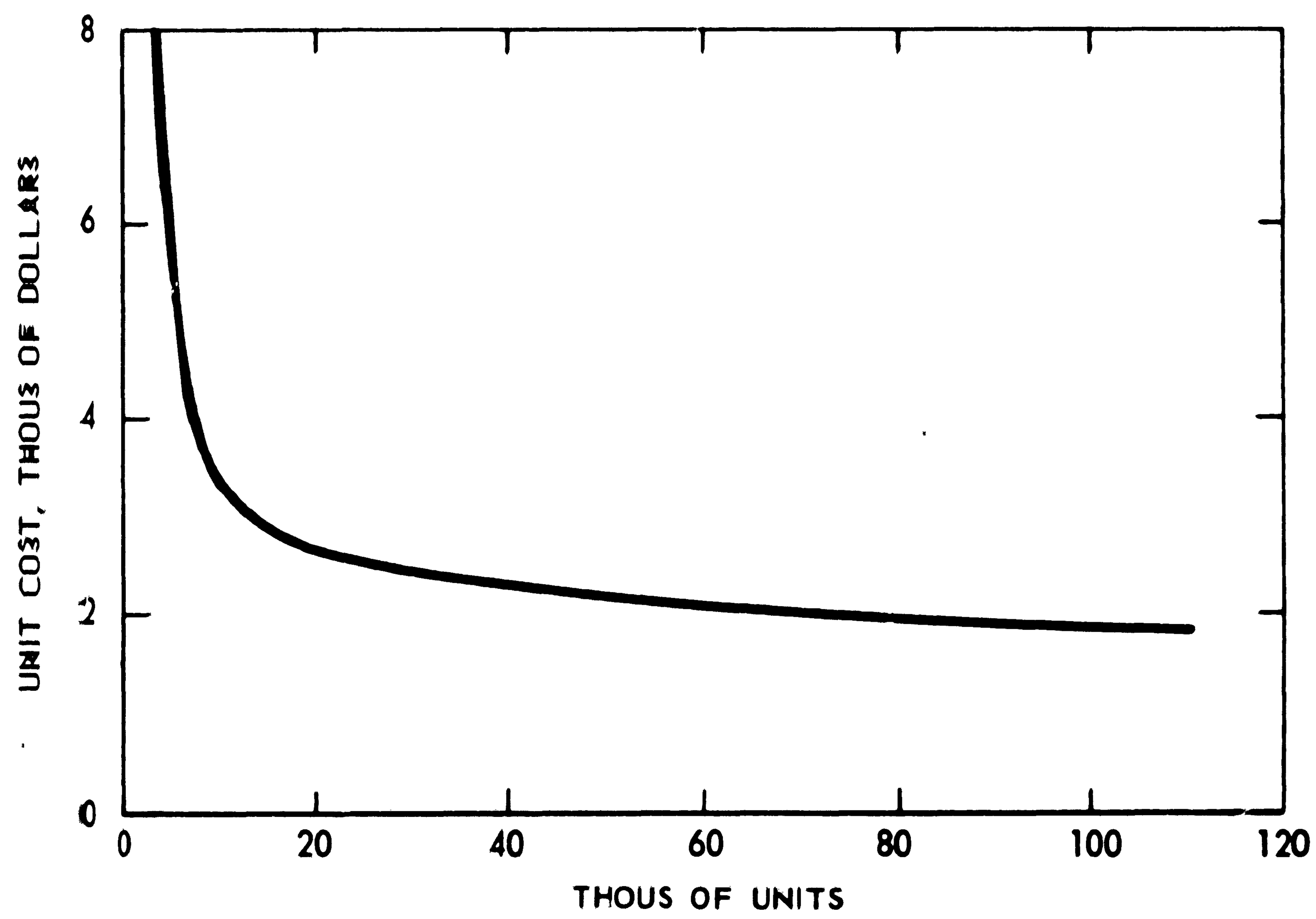

Fig. 19—Cost per Unit as a Function of Number of Units Manufactured

The potential overseas market is represented by those governments maintaining military establishments. It can be expected, though, that this market will consist of the smaller nations because many of the countries supporting large standing armies have an industrial base with excellent automotive manufacturing facilities. These countries as a rule follow the policy of buying from their own industries if they have the production capability.

American industry is presently manufacturing vehicles similar to the M151 but of much more austere design for commercial markets, both domestic and foreign, at a highly competitive price. Their market analysts are continually suggesting design modifications to meet specific consumer needs and environmental requirements. This results in many models and adaptations that provide the customer a choice of a specific configuration with the price tailored

to that configuration. The military vehicle, on the other hand, must be manufactured to meet all the requirements of all missions and environments. This is reflected in the cost, and therefore the military vehicle would not be competitive in price with the majority of the commercial market.

EFFECT ON GOLD FLOW OF SALE TO FOREIGN GOVERNMENTS

Any effect on gold flow will of course be made through our ability to sell to the other armies of the world. It is estimated that to be competitive the delivered price of a $\frac{1}{4}$-ton truck should be not more than approximately $2000.

The Kaiser CJ3B "civilian Jeep," now being furnished through MAP, costs approximately $1600, not including delivery costs. This low cost is of course associated with the high production rate. However, this vehicle does not include all the capabilities normally associated with military requirements. As shown in this study, a minimum military configuration is possible for a cost of approximately $1900. When shipping costs of about $400 are added the total cost is at a level that would probably produce very few sales.

A very high level of competition for this market will exist. Countries such as England, France, Germany, Sweden, Italy, and Japan with their relatively lower wage scales can produce vehicles with the necessary military characteristics at much lower cost.

To the question, "What impact would substantial sales of $\frac{1}{4}$-ton trucks to underdeveloped countries or to our West European allies have on our balance of payments or gold outflow?" there are two answers:

First, sales to the underdeveloped economies would not affect the US balance of payments adversely. Deficits have involved gold sales primarily with continental Europe. US expenditures in Japan, Canada, and the underdeveloped countries in excess of receipts are likely, based on past experience, to be largely compensated for by similar changes in their purchases from us rather than by purchases of gold or retention of dollar claims. Second, in Western Europe sales to allies have the beneficial effect of improving the US balance-of-payments position and reducing the likelihood of gold sales while not reducing the effectiveness of either US forces or those of our allies. The major sales program has contributed to offsetting the West German claims on dollars that have led to gold sales in the past. The critical current and future problem, at least for the next several years, lies in the gold sales to France. As a result, substantial sales of $\frac{1}{4}$-ton trucks to the French might have a very favorable effect on the US gold-supply position.

FEEDBACK OF DESIGN TRADE-OFFS AND MARKET DATA TO DETERMINE OPTIMUM CHARACTERISTICS

When selecting components for a proposed vehicle, calculated values meeting the requirements seldom coincide with available hardware. To design and manufacture components that meet the exact requirements will result in a cost much higher than can be obtained through use of components presently produced.

Since selected components that are currently produced do not necessarily meet the exact requirements, the choice will generally be the one that is most effective for its cost.

The Borg-Warner T98A transmission with the single-range transfer case was selected because it had much greater torque capabilities than the present M151 transmission assembly. The trade-off in this case, however, was a slight increase in weight.

A commercial differential and axle with power lock was selected for its low cost, but with a decrease in driver comfort.

The elimination of the electrical fuel pump in favor of the engine-driven diaphragm pump was a design trade-off to achieve a lower vehicle cost and to reduce maintenance. Additional cost savings could be realized by simplifying the fuel tank and by eliminating the oil-pressure switch, circuit breaker, and cabling. Under specific, rare conditions some loss of reliability due to vapor lock can be expected.

The deletion of the waterproofing requirements on the engine starter would reduce cost, but the components could not be submerged in water.

The elimination of the leakproof test, flanged pipe connections, tail-pipe extension, and commercial cold-rolled steel for the muffler was considered a design trade-off for the vehicle's fording capability and cost. The pipe extension would be added as extra length to the exhaust or tailpipe. The complete muffler would be fabricated from stainless steel, which would increase the muffler's life approximately 200 percent at a cost increase of only 50 percent.

A commercially available mirror was traded for a Mil Spec mirror. The commercial version is cheaper, less complicated, and will perform the same function. However, this mirror is not fungus resistant.

Military specified wheels were traded for commercially available wheels. These wheels are less expensive but are not interchangeable with those of other military vehicles.

The vehicle in the proposed QMR will have reliability and maintainability comparable to that experienced in the M151. This reliability and maintainability cannot be appreciably increased by a nominal increase in cost.

The austere vehicle described in this study can be obtained at a cost of $1900 per unit but reliability and maintainability will be decreased.

The recommended vehicle described in this study can be obtained for $2250, which is less than the cost of the present M151 and will have increased reliability and maintainability.

VEHICLE SYNTHESIS

VEHICLE SATISFYING THE QMR

This study has revealed that a vehicle can be produced to meet all essential requirements specified in the QMR except reliability. A 90 percent probability of operating the vehicle for 15,000 miles without need of a minor overhaul and 25,000 miles without need of a major overhaul is questioned. The present M151 vehicle has attained a 90 percent capability when evaluated against a 10,000- and 20,000-mile durability test over 6000 miles cross-country, 6000 miles on secondary roads, and 8000 miles on highways. The requirement of a 90 percent capability of a 15,000- and 25,000-mile test criterion is much more difficult or may even be impracticable. Industry has not advanced the state of the art sufficiently to be able to state with any assurance that this could be accomplished at even twice the cost of the present vehicle. A definition of reliability or probability of operating a vehicle for a given number of miles should be clearly stated in the QMR, since personnel in industry and government have various interpretations of this requirement.

This vehicle, however, would have a 75-mile/day mission reliability of 95 percent carrying a 500-lb payload, plus driver and passenger. It would have an inherent floating capability and would be self-propelled in the water by wheels only at an estimated speed of $1\frac{1}{2}$ mph. This vehicle would have the capability of negotiating 60 percent longitudinal and 40 percent lateral slopes. The brakes would be capable of stopping the vehicle within 30 ft at 20 mph on a level dry road. It would have a cruising range of 300 miles with payload and towed load while operating 30 percent on paved roads, 40 percent on secondary roads, and 30 percent cross-country. This vehicle would have a sustained top speed of 60 mph on level roads and could be driven at a minimum of $2\frac{1}{2}$ mph. The engine would have sufficient power to permit operation of the vehicle at a speed of 30 mph on a 6 percent grade with full payload and towed load. The engine would have sufficient horsepower to meet the weight ratio of 30 hp/ton minimum. The vehicle steering geometry and vehicle size would permit a wall-to-wall turning radius of 18 ft. This vehicle could also meet the storage-degradation requirements. It would be capable of being airdropped with proper equipment, and its towing hitch would be compatible with the present $\frac{1}{4}$-ton trailer. The gasoline engine would limit the liquid fuel range to 80-octane gasoline, and the vehicle would not be capable of propelling itself in the water at the desired 4 mph. This vehicle would contain a glove compartment, lifting and tie-down eyes, turn signals, spare tire, and a 24-v electrical system fully radio suppressed with a 60- to 70-amp alternator. The vehicle angle of approach would

be at least 60 deg and the angle of departure, 45 deg. The vehicle's estimated weight would be within the maximum curb weight of 2700 lb and would have both two-wheel-and four-wheel-drive capability. The required time between scheduled maintenance would be met. This vehicle would be produced to accept various kits such as arctic, personnel heater, desert, slave, communications, HAW, and light-machinegun kits. The desired target unit cost would not be met. In all other respects the vehicle meets the QMR.

The estimated cost of a vehicle meeting the requirements in the QMR, but with a presently attainable reliability factor, would be $3200 in production quantities of 10,000 per year for 3 years.

AUSTERE VEHICLE

This study has revealed that a vehicle can be produced at the desired target price of $1900, but it would not meet all the essential requirements specified in the QMR. The two major deficiencies would be reduced reliability and absence of the desired floating capability. Many design trade-offs were theoretically applied to reduce the cost, but at the expense of reliability, durability, and performance.

All major components of the vehicle were evaluated in detail by comparing M151 military specification (Mil Spec) components with commercially available components.

After a thorough analysis of various available components and their compatibility with selected components, cost savings were estimated by contacting component manufacturers now supplying military or commercial items and by compiling present spare-parts data available to the government. Spare-parts cost data were discounted for normal markups in arriving at the unit cost.

Major cost-saving components are:

<u>Carburetor</u>. A commercially available carburetor was substituted for the Mil Spec carburetor, which has special features for attaching the fording kit. In addition the Mil Spec carburetor has a bowl that is modified to prevent binding while the vehicle is operating on grades of 60 percent. The commercial carburetor has a tendency to vapor lock in high-ambient-temperature environments.

<u>Fuel Pump.</u> The present $1/4$-ton truck incorporates an electric fuel pump mounted inside the gasoline tank. This pump would be replaced by an engine-mounted diaphragm pump with a vacuum booster. This pump would be less positive but is generally considered satisfactory.

<u>Muffler.</u> The present Mil Spec muffler would be replaced by a commercially available muffler meeting the commercial standards of two or three acceptable vendors. This muffler would eliminate the requirement of welding the seams and would utilize conventional clamps. It would not be acceptable for deep-water fording.

<u>Starting Motor</u>. The Mil Spec starting motor would be replaced by a commercially available motor whose main components are in high-volume production. The motor mount would have to be modified to match the engine and would not be waterproof.

Generator. The Mil Spec generator would be replaced by a commercial alternator modified to incorporate radio suppression. This alternator would have better generating characteristics at lower engine rpm but would not be waterproof.

Batteries. Since the electrical system would be a 12-v system, only one Mil Spec battery, instead of two, would be required.

Transfer and Transmission. The present Mil Spec transfer and transmission would be replaced with a commercial Warner Gear SK4570C. These components are in high production and would provide good vehicle reliability and performance, but at the cost of some additional weight.

Differential. The present Mil Spec differential would be replaced with a commercially available differential presently in high production and would have good reliability and performance. It would not be interchangeable with other military vehicles such as the $^3/_4$-ton 6 × 6 truck.

Brake Assembly. This assembly would be in accordance with the Mil Specs except that it would incorporate commercial plating and preservation.

Wheels and Tires. The present Mil Spec 7:00-16 4-ply nylon tires would be replaced with commercial 6:70-15 2-ply rayon tires and would utilize high-production commercially available wheels.

Engine. The present Mil Spec engine specifications would be modified to take advantage of commercially available components that meet all requirements but do not comply with present Ordnance drawings. This would permit component parts such as bearings, rings, and valves to be purchased from competitive sources. Performance and reliability would not be affected.

Vehicle Body. The present M151 body requires approximately 4000 spot welds. It is estimated that with some redesign this number could be reduced to 2600. Also, 1010 sheet steel would be substituted for 1017, and commercial paints would be used for protective finish where possible.

Rear-Seat Assembly. The rear seats would be eliminated and provided as a kit when needed.

Front-Seat Assembly. The design of the front-seat assembly would be simplified, and passenger-seat adjustment would be eliminated.

24-v Switch. This switch would be eliminated since the engine-mounted fuel pump was substituted for the electric pump mounted in the fuel tank.

Towing Eyes. The towing eyes were eliminated because towing frequency for this vehicle is relatively low, and other methods of towing the vehicle could be substituted when needed.

Circuit Breaker. The circuit breaker was eliminated with the elimination of the electric fuel pump.

Wire Harness. Replace the Mil Spec wire harness with a good grade of commercially available wire. This may have some effect on radio suppression.

Horn. Replace the present Mil Spec horn with a commercially available horn. This horn would not be waterproof.

Ignition and Starter Switches. Replace the present Mil Spec ignition switch and starter switch with commercial switches. These switches would not be waterproof.

Air-Drop Eyes and Nuts. Replace the present air-drop eyes and nuts with commercial hubcaps. The eyes and nuts can be provided in the air-drop kits.

Door and Curtain Assemblies. The door and curtain assemblies would be eliminated on all basic vehicles but would be provided as a kit where needed.

Passenger Windshield Wiper. This windshield wiper would be eliminated because it is not necessary for satisfactory vehicle operation.

Miscellaneous Items. Eliminate many of the miscellaneous items such as the air-cleaner inlet panel on the hood, axe, shovel, gas-can straps, etc. Provide as a kit when required.

Wheel Nuts. Replace the present $^7/_{16} \times 20$ studs and floating flange nuts with standard high-production $^1/_2 \times 20$ studs and nuts. This would not affect reliability.

Oil-Pressure Switch. The oil-pressure switch would be eliminated since it would not be required with the engine-mounted diaphragm fuel pump.

Right Air Vent. This vent would be eliminated since it is not necessary for satisfactory vehicle operation.

Floor Drains. The floor drains could be eliminated since they are not necessary for vehicle operation, particularly for a vehicle without floating or fording capability.

Undercoat. Undercoating would be eliminated since corrosion has not been a problem and present paints provide sufficient protection.

Various Rubber Parts. Replacement of present -65°F Mil Spec requirement on rubber items with commercially available - 25°F rubber components would not affect reliability.

Hose Clamps. Replacement of present Mil Spec stainless-steel clamps with commercial steel clamps would not affect reliability.

Rear-View Mirror. Replace the present Mil Spec rear-view mirror with a commercially available mirror. This mirror would not be hermetically sealed but has a good gasket and basically accomplishes the same result.

Fuel-Tank Cap. Replace the present Mil Spec cap with a commercially available cap.

Radiator Cap. Replace the present Mil Spec cap with a commercially available cap.

Although this vehicle could be produced at the desired target cost it is doubtful that it would be the most effective vehicle for its cost. No combat profile has been established as a reasonable performance to meet the combat conditions visualized. The vehicles are generally employed worldwide and environmental extremes can be determined, but data on essential factors such as soil trafficability and frequency of employment under specific field conditions such as marshy terrain, difficult hill slopes, and stream fording are lacking. However, these vehicles at various times must perform missions that demand the ultimate in ruggedness, reliability, and sustained high performance. Operating personnel, whether trained or untrained, may be required to obtain maximum performance from the vehicle over long periods in order to complete their mission. Proper maintenance may be neglected during combat, and the useful life of an austere vehicle may be many times less and maintenance many times more than that of a vehicle with more rigid specifications. The austere vehicle that meets the target costs results in major degradation of cross-country mobility as compared to the M151. Many items, specifically described in the section "Technical Analysis of the Vehicle," are not always of overriding importance individually. Collectively, however, the unacceptably adverse effect on

cross-country mobility is evident. The austere vehicle would not be appreciably lighter in weight for transportability considerations; and spare parts presently in the system could not properly support the vehicle.

On the other hand, should these vehicles be used primarily for various administrative, general utility, and troop-training purposes during peacetime, the austere vehicle could well suffice.

It is recommended that a compromise between the present rigid Mil Spec and the foregoing suggested relaxation of the specifications be considered.

RECOMMENDED VEHICLE

As a result of this study it is believed that a vehicle should be designed and produced that meets the QMR as nearly as possible within the limits of a reasonable cost. Since good design alone requires trade-off, reliability was stressed, considering both initial and total operating cost. This proposed vehicle will meet all basic requirements of the QMR except the inherent floating capability and the probability of operating 15,000 miles without a need for minor overhaul and 25,000 miles without a need for major overhaul. A technical analysis was made of every major system, and various components were analyzed to determine which would result in a most effective vehicle for its cost.

It has been decided as a result of this analysis that the power-train system should incorporate a domestically manufactured liquid-cooled gasoline engine. The present M151 engine, Army Part No. 8754411, was selected as a reliable component. This engine has operated under severe conditions, and as a result of tests many modifications were incorporated to improve its reliability. In order to reduce some costs it is recommended that this engine incorporate some commercially available parts that would permit competition from two or three sources. These parts would be limited to rings, rod bearings, and valves that are now produced in high quantities.

For a second source engine, this study has revealed that the commercial Kaiser Jeep engine is acceptable if modified to meet various requirements such as the deep oil pan for 60 percent grades, more rugged seals and bearings, and other components of a minor nature.

A number of transmission-transfer boxes were analyzed for compatibility with the recommended engines and the vehicle tests. The analysis showed the Borg Warner gear T98A to be the first choice. This is a four-speed transmission fully synchronized with the newly developed single-range transfer case. The transmission is produced in high quantities and has had satisfactory service in trucks requiring twice the torque of the present ¼-ton truck. The reliability of this transmission would be extremely high but at the cost of 80 lb additional weight.

The second-choice transmission would be the Borg Warner T90C, which is now installed in the M38A1 vehicle. This is a three-speed transmission with a two-speed transfer box. The transfer-box gears are not synchronized and are therefore much more difficult to operate.

The third-choice transmission would be the present M151 Army Part No. 7536199 transmission with a single-range transfer case. The transmission has been especially designed for the ¼-ton truck and has performed

satisfactorily. However, the main objection is the cost, since it is produced in relatively low volume.

A number of differentials and axles were analyzed prior to making a recommended choice. It has been determined that the present M151 axle is relatively expensive and incorporates a through shaft for both the front and rear axle, primarily for interchangeability with those of the $^3/_4$-ton trucks. The differential does not incorporate a power lock, since space did not permit this within the design. The omission of this feature would result in some loss of mobility. It is therefore recommended that the Dana Models 44 and 44-3 differentials and axles containing the power-lock feature be incorporated. These differentials are available now in large-quantity production and can be purchased for approximately half the cost of the present M151 differential. It is the writers' opinion that this differential would provide satisfactory performance and reliability.

The vehicle suspension system was analyzed for its reliability, durability, operator's comfort, and cost. The present M151 incorporates individual coil-spring suspension, which results in smooth riding characteristics. The cost of this smooth ride is considerably higher than that of a vehicle incorporating individual wheel leaf springs. Statistical data in the field have indicated that this smooth riding feature has resulted in a higher accident rate because of the driver's loss of "feel" of terrain conditions. It is recommended that leaf springs be incorporated; they would be less costly, would maintain vehicle re. . ability, and would provide more physical space in the engine compartment, thus allowing the designer more flexibility in locating associated components.

Standard heavy-duty wheels are recommended to replace the $^7/_{16} \times 20$ studs and floating flange nuts with standard $^1/_2 \times 20$ studs and nuts. A high-grade military tire would be retained.

Various materials were considered for the vehicle body, but this analysis has shown that steel bodies provide satisfactory service at a reasonable cost. Plastic bodies were found to be too expensive, and aluminum bodies were found to be quite difficult to maintain. It is recommended that some of the individual components be redesigned to eliminate many of the spot welds in the present M151 body design, with a corresponding decrease in cost.

A complete electrical analysis was made to determine areas where cost could be reduced. It was determined that a substantial cost savings could be realized if the vehicle incorporated the commercial 12-v electrical system. This system would not meet the requirements for various reasons, however: (a) the vehicle would be more difficult to start in cold weather, (b) the electrical system would admit radio interference, (c) a special kit would be required to provide power for the radio of the communications vehicle, and (d) the slave cable could not be plugged into any other military vehicle for a source of power.

It is therefore recommended that the 24-v radio-suppressed electrical system be retained and as many commercially available components as feasible be incorporated.

The vehicle's exhaust system was analyzed, and it was determined that the clamps for the exhaust and tail pipe could be simplified, or commercially available clamps could be utilized at a lower cost. The muffler should be constructed of stainless steel, which would result in additional service life. The

stainless-steel muffler would in all probability increase the muffler's original cost 50 percent while increasing its life 200 percent.

A user survey was made to determine how often the vehicles were subjected to deep-water fording. This survey showed that vehicle commanders found deep-water fording impractical and had devised other means to accomplish this mission. Deep-water-fording capability required many features in the vehicle that were expensive and required extensive maintenance. It is therefore recommended that deep-water-fording requirements be eliminated. This would in turn result in a more reliable vehicle.

During this study continuing value analysis was made of both the vehicle and its component parts. Many areas were found where drawing specifications were more stringent than required. A typical example is the Mil Specs on rubber compounds. These called for certain physical characteristics at -65°F. Since these vehicles would not normally be operated until heated by a winterization kit, and since flexing automatically raises the internal temperature of the rubber, it is felt that products meeting the -25°F specification could be purchased at half the cost of the higher-specification rubber compounds. The rear-view-mirror, fuel-tank-cap, and radiator-cap costs could be reduced by specifying commercially available items in lieu of those meeting present Mil Specs. The vehicle's reliability and performance capabilities would not be reduced.

It is estimated that the recommended vehicle as described could be designed and produced for a cost of $2250.

The floating requirement as requested in the present QMR would require redesign or modification of many of the components. This would in turn reduce the number of standard commercially produced components that could be incorporated, which would proportionately affect the cost. In addition the vehicle body would have to be constructed watertight with its sides raised to at least 10¾-in. freeboard. It is the opinion of the writers that the water speed by means of wheels only would not be satisfactory. Ease of maintenance would be reduced, reliability would be questionable, and land-performance capabilities would be compromised for water capabilities. It is estimated that this vehicle could be designed and produced for $2770.

A study was also made on the ¼-ton truck that would have amphibious capabilities. This design was based on the vehicle's having good trim and stability characteristics and a water speed of 4 mph. In order to accomplish this the payload would have to be placed in the center of the vehicle with the engine aft and driver forward. This arrangement would require either a great number of modifications to standard components or a completely new design. Also this design would require some compromise on land mobility, vehicle maintainability, reliability, and cost. It is estimated that this vehicle could be designed and produced for a cost of $3200.

For the reasons stated, it is therefore recommended that the proposed military requirement for the ¼-ton utility truck be restated to include the above recommended modifications, and to exclude the floating and amphibious requirements. This would produce a reliable vehicle for both peacetime and wartime operations and would be the most effective vehicle for the cost.

IMPORTANCE OF VEHICLE WEIGHT

An investigation was undertaken to determine the effect of vehicle net weight on land-transportation cost and air-transportation range.

Regarding the former it was determined that basically the cost of transporting $\frac{1}{4}$-ton trucks by rail or highway is independent of vehicle weight. Rail costs are based on the number of vehicles (loading charge), the cost per rail car (bi- or trilevel), and distance considerations (points of origin and destination). Truck costs are determined on a cost per vehicle basis that, for a given point-of-origin—destination combination, is a constant for all vehicles within specified weight classes (i.e., 3200 lb or less, 3200 to 3500 lb, etc.).

The method of cost calculation for rail and highway vehicle transportation is as follows:

Rail cost = number of vehicles × loading charge per vehicle + (number of vehicles/number of vehicles per rail car) × cost per rail car *

Highway cost = number of vehicles × cost per vehicle†

Air-transport range is inversely proportional to cargo weight within the capacity limits of the aircraft. The relations between weight and sea-level standard range for the Army aircraft that are capable of transporting one or more $\frac{1}{4}$-ton trucks are shown in Table 41.

TABLE 41

Weight Range Relations for Army Aircraft

Aircraft	Increase in wt, lb, causing 1-NM decrease in range
Caribou (CV-2B)	3.5
Caribou (CV-7A), STOL	8.7
Iroquois (UH-1D)	6
Chinook (CH-47)	155

TABLE 42

Decrease in Range with 250-lb Increase in Truck Weight

Aircraft	Decrease in range, NM	Nominal range, NM
CV-2B	72	975
CV-7A, STOL	29	800
UH-1D	42	180
CH-47	1.6	240

An increase in truck weight of approximately 250 lb, which would be required to obtain a floating capability, would not affect the ability of the aircraft to carry the vehicle but would result in the decrease in range shown in Table 42.

A preliminary investigation was also performed on the effect of vehicle gross weight on engine characteristics. It was concluded that the engines under consideration contained enough reserve output capability to perform satisfactorily (i.e., per specification) with the added 250 lb of vehicle weight. It was also determined that the fuel consumption of the engine is inversely proportional to the gross weight (with all other conditions fixed) and would therefore decrease for a 250-lb weight increase from 17 miles/gal for 3600 lb to 17 × 3600/3850 = 15.9 miles/gal for 3850 lb.

* Based on point of origin and destination.
† Based on point of origin and destination and vehicle weight class.

Appendix A

Proposed Qualitative Materiel Requirement for Truck, Utility, $\frac{1}{4}$-Ton [CDOG Para 1636c(9)]

Section I - Statement of Requirement

1. Statement of Requirement

a. Truck, Utility, $\frac{1}{4}$-ton

b. An austere, low cost, personnel and weapons carrier with a rated payload of $\frac{1}{4}$ ton. Its mile-per-gallon fuel consumption must equal or be improved over that of current $\frac{1}{4}$-ton truck. It must have a minimum cruising range of 300 miles of travel without refueling. An inherent swimming capability within the limitation of a nominal increase in cost is desirable. It must be air-transportable in Phase II of airborne operations without sacrifice of durability or reliability. This vehicle will replace the Truck, Utility, $\frac{1}{4}$-ton, 4×4, M151. It will be used on and off roads, and may be used throughout the theater of operations, in close support of fighting vehicles and troops as a command and communication vehicle; as a carrier for personnel and weapons; and should be capable of towing standard $\frac{1}{4}$-ton trailers. (TF 63-67)

Section II - Operational, Organizational and Logistical Concepts

2. Operational Concepts

a. Although this vehicle will be used in combat, combat support and combat service support units, its adaptability to tactical utilization should receive primary consideration. It is intended to provide mobility commensurate with the concept of dispersed operations. This quality will permit command and control elements to operate across the same type terrain as the units to which assigned, and will permit greater dispersion on a wide front. It will be employed in Phase II of airborne operations. With the addition of kits this vehicle may be used as a weapons carrier.

b. It must be capable of being operated in all seasonal conditions with a mission reliability of 95% with none other than driver maintenance and in subarctic and tropical climates with a mission reliability of 95% by the use of modification kits. This mission is defined as operations in a combat zone for a period of six days with an average utilization of 75 miles/day consisting of operation at safe operating speeds, 40% of which is idling, 40% cross-country and 20% over secondary roads. This vehicle will be used in the temperate, subarctic and tropical zones and in jungle, desert, mountainous and savanna-type terrain. It must have the capability to negotiate commonly encountered terrain types and obstacles, including shallow ditches, bushes, grass, shallow streams and beaches, and to pass moderately forested and rocky areas over routes receiving some preparation.

c. This vehicle will be used in theaters of operations as stated in paragraphs 7a(7) and 8a(22). Such operations will include around-the-clock and all-weather use, with an average utilization rate of 75 miles/day.

d. This vehicle will be required to perform the missions presently accomplished by the standard $\frac{1}{4}$-ton truck. (This requirement will be reduced by missions to be performed by the M114 Command and Reconnaissance Carrier, the $1\frac{1}{4}$-ton ambulance and

the $1\frac{1}{4}$-ton Command and Weapons Carrier.) It will be capable of attaining highway speeds comparable with other current standard or developmental trucks (and when operating off-road to maintain continuous forward movement). The vehicle will be required to perform its mission as far forward in the combat zone as deemed tactically advisable, and for a duration of up to six days as stated in preceding paragraph 2b.

e. Emphasis should be placed upon the ability of the vehicle to perform over extended periods of use with only scheduled organizational maintenance and without failure of accessories or integral major components.

f. The time to service the vehicle for recommitments or dispatch shall not exceed 15 minutes assuming no repairs are required.

3. Organizational and Logistical Concepts

a. This vehicle may be organic to all arms and services, their support elements and administrative units. It is anticipated that this vehicle will be a replacement item for many of the present $\frac{1}{4}$-ton trucks.

b. Replacement of some of the present $\frac{1}{4}$-ton trucks by this vehicle will require a similar number of vehicle operators based on driver-to-vehicle ratios approved in current TOE's.

c. Logistical considerations of supply and resupply factors should be reduced as compared to those in effect for current $\frac{1}{4}$-ton vehicles.

Section III - Justification, Feasibility and Priority

4. Reasons for Requirement

a. In July 1960, CRD advised USCONARC that the approved Army development program for wheeled vehicles had not been fully implemented and was not fully compatible with future operational concepts. Reappraisal of the Army's requirements was directed. In October 1960, USCONARC forwarded the results of this study. Development of a fleet of wheeled vehicles in 6 payload categories was recommended to include a new $\frac{1}{4}$-ton truck to replace the current standard M151 $\frac{1}{4}$-ton truck.

b. In addition, on 26 August 1963, Department of the Army directed that a QMR be developed for a new $\frac{1}{4}$-ton truck with sheer useful functionalism. In this QMR the focus should be on simplicity, durability, ease of operation and maintenance, and reduced cost in relation to the M151.

c. This vehicle is required to fulfill the tactical mobility requirements envisioned in the time frame of the RODAC-70 study.

d. Pertinent CDOG references:

110.c	310.c(2)
112.a	410.c(6)
112.c	836.b(8), (15)
210.c(2)	1610.c(8)
	1612.a

e. Other References:

(1) Study, "Water Crossing Requirements for Vehicles," Hq USCONARC, 16 February 1959.

(2) Study, "Motor Vehicle Requirements, Army in the Field, 1965–1970 (MOVER)," Hq USCONARC, 25 October 1960.

(3) Study, "Reorganization Objectives, Division, Army and Corps - 1970 (U)," (CDOG Project 61-8), U. S. Army Command & General Staff College, Fort Leavenworth, Kansas, 1 November 1961.

(4) MIL-STD 1228, Maintainability Criteria for Tank-Automotive Materiel, 27 September 1962.

(5) Study, "Logistical Vehicle Off-Road Mobility" (TCCD 62-5), U. S. Army Transportation Combat Developments Agency, Fort Eustis, Virginia, February 1963.

5. Technical Feasibility. The essential performance, physical, maintenance and human engineering characteristics are considered feasible under the current state-of-the-art.

6. Priority. Priority II.

Section IV - Characteristics

7. Performance Characteristics

a. It is essential the vehicle possess:

(1) The capability of being operated with a 500-lb payload in addition to the weight of a driver and one passenger in the temperate climate zone over various types of roads, and off roads over open rolling and hilly terrain on mud, snow and sand; over all types of terrain, under all seasonal conditions in tropic and subarctic climate zones to the maximum extent practicable.

(2) Equal or improved cross-country mobility characteristics over the current standard ¼-ton trucks.

(3) Equal or better fuel economy than that of the present standard ¼-ton truck based on miles-per-gallon.

(4) An inherent floating capability in inland waters without special preparation, as defined in AR 705-2300-8, "Water Crossing Requirements for Future Combat and Tactical Vehicles," provided such can be obtained within overall vehicle cost objectives.

(5) The capability of ascending and descending dry longitudinal slopes up to 60% with payload and of being operated on dry side slopes up to 40% with payload.

(6) The capability by driver application of service brakes, of being held and controlled when ascending and descending a dry 60% incline with payload, and of being brought to a stop on a dry level roadway within 30 feet from 20 mph with payload.

(7) The capability, with rated payload and towed load, of being operated for at least 300 miles, at average safe operating speeds, under average conditions over representative courses which consist of 30% highway, 40% secondary roads and 30% cross-country, without refueling. Its battlefield day performance under the combat vehicle criteria of 40% idling, 40% cross-country and 20% secondary road operation shall not be less than that of associated tanks, APC's, etc.

(8) The capability of being operated on dry, level, hard-surfaced roads at a sustained speed of at least 50 mph and at a minimum sustained speed of 2½ mph.

(9) The capability of maintaining a speed of 30 mph on a dry 6% grade while handling full payload and towed load.

(10) A horsepower-to-weight ratio of at least 30 hp/ton of gross vehicle weight.

(11) A maximum wall-to-wall turning radius of 18 feet.

(12) The capability of mounting and operating current and developmental radios and prescribed on-vehicle equipment of sizes and weights appropriate to the vehicle's rated payload.

(13) The capability of towing a ¼-ton trailer with its rated payload.

(14) The capability of required performance with fuel, lubricants, hydraulic fluid, antifreeze compounds, preservatives and other service materials meeting the minimum quality of the latest revisions of the applicable standard specifications insofar as the use of such materials is required by design of the equipment.

(15) A 90% probability of being operated for 15,000 miles with only scheduled organizational maintenance without failure of either accessories or integral major components, and for 25,000 miles without the need for major overhaul or the replacement of a major component.

(16) The capability of operation and storage in the basic operating conditions prescribed in paragraph 7a of AR 705-15. In addition, with the use of special purpose kits, the vehicle must be capable of operating under the conditions specified in paragraphs 7b and 7c of AR 705-15. In order to exploit its full potential, the special purpose kits must be developed concurrently with the development of the vehicle.

(17) A degradation from depot storage for one year of no greater than 3% in ready rate or mission reliability, and from field storage for six months no greater than 6% in ready rate or mission reliability.

(18) Vehicle body will be of such construction as to provide adequate structural members and space for attachment of kits, including weapons and radios.

b. It (is) desirable that the vehicle possess the following, provided they can be obtained within overall vehicle cost objectives:

(1) The capability of operation on a wide range of liquid petroleum fuels.

(2) Be capable of employment in Phase I airborne operations.

(3) Be capable of self-propulsion over inland waterways at speeds of up to 4 mph without special preparation.

(4) Compatibility with the present $\frac{1}{4}$-ton truck trailer if feasible.

8. Physical Characteristics.

a. It is essential that the vehicle possess:

(1) A payload capability of 500-lb plus the weight of driver and assistant driver.

(2) Minimum overall dimensions consistent with other requirements and shall not exceed the limitations of AR 705-8 insofar as practicable.

(3) Wheels as a means of land locomotion.

(4) The capability of transporting at least 4 personnel (including driver) and their individual combat equipment and arms; or driver and assistant driver plus rated payload.

(5) A provision for stowage of vehicular tools and equipment and the individual weapon for the driver.

(6) A provision for the stowage of a spare tire or other device which will provide a "get-home" capability. Subject item will not occupy any of the cargo space and will be accessible when the vehicle is loaded.

(7) A container, preferably built into the vehicle dash, of sufficient size to hold operations manual, equipment log book, accident report forms and other required publications and forms.

(8) Suitable means for lifting and tie-down devices for rail, air and marine transport, including external transport by helicopter.

(9) Turn signals. These will not be operable under blackout conditions.

(10) Sufficient clearance to permit the use of tire chains or traction devices.

(11) The current military standard 24-volt ignition and lighting system, fully radio suppressed and waterproofed, with a 60-70 ampere alternator.

(12) Standard military accessories, such as brush guards, towing pintle, trailer electrical receptacle, reflectors, tow hooks, lifting eyes, and oil and fuel filters, provided cost objectives are maintained.

(13) An angle of approach of not less than 60 degrees.

(14) An angle of departure of not less than 45 degrees.

(15) The maximum ground clearance possible without compromise of other essential characteristics.

(16) All-wheel drive with means for manually disengaging front wheel drive when not needed.

(17) An economical manual shift transmission-transfer.

(18) The capability, with payload, of being air-transported in Phase II of airborne operations.

(19) A capability of overseas transport and landing over beaches in service-ready condition. Particular attention shall be given to the avoidance of materials which suffer rapid deterioration as a result of exposure to salt-laden atmosphere and to salt water.

(20) A capability, with payload, of internal transport by cargo helicopter of the FY 68 and beyond time frame and internal transport in fixed-wing Army transport aircraft.

(21) The capability of being transported by rail and highway within the confines of AR 705-8.

(22) Sufficient ruggedness to withstand military service for extended periods of time with minimum servicing. Average normal mission duration is estimated to be six days.

(23) Materials to provide adequate resistance to rust, corrosion and deterioration in service and storage. (To include resistance to salt spray and salt water.)

(24) Maximum safety provisions for personnel and equipment during the operation, storage, transportation, and maintenance phases of the life of this equipment. Such items as hand holds, safety straps, guards around heat sources and moving parts, and warning signs or decals must be provided.

(25) Maximum vehicle stability during operation at all speeds through design speed.

(26) Protection from inclement weather for personnel and payload.

(27) The capability of operation in the extremes of environment, with the addition of kits.

(28) A windshield design which will afford protection from brush and overhanging tree limbs, and for folding and locking to the horizontal and/or removal.

(29) A minimum practicable curb weight, consistent with other characteristics, this weight not to exceed 2700 lb. Performance, durability, reliability, and ease of maintenance will not be compromised to achieve weight reductions.

(30) A capability of being slung externally from the utility helicopter of the FY 68 time frame and beyond.

9. Maintenance Characteristics

a. It is essential that the vehicle possess:

(1) Design characteristics for minimum practicable preventive and in-storage maintenance. The vehicle should be designed to facilitate maintenance at all echelons, in minimum time, by personnel with the least practicable degree of skill, and with the least variety and complexity of tools, equipment, and supplies. To satisfy this requirement, modular or throwaway component assemblies or parts should be used whenever practicable. Maximum accessibility shall be provided to high mortality components. Design for ease of maintenance should not take precedence over design for increased reliability.

(2) Maximum internal interchangeability and use of commercially available standard components, parts, and modules, where feasible.

(3) Permanent lubrication to the maximum extent possible, commensurate with overall cost objectives.

(4) Minimum allowable time between scheduled echelons of maintenance as follows:

(a) Organizational maintenance - 6 months

(b) Field maintenance - 1 year

(5) A reasonable minimum variety and quantity of replacement modules and repair parts required for stockage at organizational level.

(6) Simplicity in design so that the skill level required to perform maintenance (organizational and field) on this vehicle shall not exceed that required for MOS 635 (Automotive Repairman).

b. It (is) desirable that the vehicle possess:

(1) Major components (e.g., engine, transmission, axles, suspension, etc.) that are maintenance-free throughout the service life.

(2) Inherent characteristics so that major overhaul or rebuild (5th echelon maintenance) of the vehicle or its components is not required.

(3) Maximum and mean time allowable for diagnosing failures as follows:

(a) Organizational maintenance: Mean time 20 minutes, maximum 30 minutes.

(b) Field maintenance: Mean time 90 minutes, maximum 2 hours.

(4) Maximum allowable time for making repairs as follows:

(a) Organizational maintenance - 4 man-hours

(b) Field maintenance - 12 man-hours

10. Human engineering Characteristics. The vehicle should be designed in conformity with human factors engineering principles wherever possible within the overall cost objective. Particular attention should be directed to the design and location of controls and instruments at the operator station. Special consideration should be given to increasing the efficiency of those maintenance operations which cannot be completely eliminated.

a. Vehicle Design

(1) Seats. Driver seat is adjustable for tall and short men and driver and passenger seats are designed to fit the back and buttocks of the 95 percentile man.

(2) Controls

(a) The steering control-operator seat relationship shall permit safe, easy, and comfortable driving.

(b) The control requires as few movements as possible.

(c) Successive control movements are interrelated, i.e., one movement passes easily into the next.

(d) Controls used in rapid sequence have uniform direction of motion.

(e) Control movements are consistent for all equipment which one operator uses.

(f) The method used to prevent accidental activation of the control, if any, does not increase the time required to operate the control to such an extent that it is unacceptable.

(g) Activation of the control does not obscure visual display or control markings, if possible.

(h) Controls such as clutches and foot throttles are located in such a manner that they can be operated easily without the driver having to assume uncomfortable body angles. Controls of this type are also capable of being operated easily when the driver is equipped with thermal boots (Mickey Mouse boots).

(i) Foot throttles are so located that the driver, with minimum amount of movement and effort, can remove his foot from the throttle and apply the foot brake.

(j) The driver has the capability of applying the brakes easily when thermal boots are worn.

(k) The instrument panel is so located that it can be observed from the normal driving position.

(l) Visual indicators are provided for notification when engine temperature, oil pressure, and electrical system are above or below safe operating ranges.

(3) Displays

(a) Information presented will be the minimum necessary for the basic decisions or actions required of the operator in regard to safety and maintenance.

(b) Displays will be simple in design and will present information in the most immediately meaningful form, i.e., no interpretation or decoding is required.

(c) Information is displayed to the accuracy required by the decisions or actions of the operator, and preferably no more accurately than required.

(d) If scale interpolation is required, it does not introduce a probability for operator errors which are greater than the operator's task permits.

(e) Information for different types of activities, e.g., operation and maintenance, is not combined unless the activities require the same information.

(f) Information is current. i.e., lag is minimized.

(g) Failure in the unit is clearly shown or the operator is otherwise warned.

(4) Base and safety of operation.

(a) Adequate means are provided for the driver to get in and out of the cab when wearing cold-weather clothing.

(b) OVE tools are located where they are easily accessible.

(c) Safety straps across the doorway on the driver and passenger sides.

b. Maintainability Design

Handles, covers, cases, access doors, components, conductors, cables, conduits, connectors, test points, fuzes, circuit breakers, tools, and lubrication points will be designed to permit easy access, to reduce wear, and to facilitate easy maintenance in compliance with human factors engineering criteria wherever practical.

11. Priority of Characteristics in Order of Importance:

a. Performance
b. Physical
c. Maintainability
d. Kits
e. Transportability
f. Environmental factors

Section V - Personnel and Training Considerations

12. Quantitative and Qualitative Personnel Considerations

a. The number of personnel required to operate and maintain these vehicles should be the same as the number required for the current 1/4-ton truck, less personnel requirements to operate and maintain the M114 and 1 1/4-ton vehicles substituted for the 1/4-ton truck.

b. The present operators and vehicle mechanics will be capable of operating the vehicle.

13. Training Considerations. Operators will not need any special training other than familiarization with the vehicle.

Section VI - Associated Considerations

14. Training Devices. The vehicle and its components will be the only training device requiring development.

15. Related Materiel

a. Development of special purpose kits shall be concurrent with development of the vehicle. All kits required shall have the following features:

(1) Be designed for installation by organizational means.

(2) If any kit requires power, provisions must be made for conversion of power available from the vehicle to a suitable form for use by the particular kit. Power outlets, including electrical, shall be provided on the vehicle.

b. The following kits are required:

(1) Arctic (-25° to -65° F)
(2) Personnel Heater (-25°)
(3) Desert (125°)
(4) Slave
(5) Communications Installation
(6) Light machine gun
(7) Heavy Anti-Tank/Assault Weapons System (HAW)

16. Cover and Deception: None

17. Probable interest. It is probable that the British, Canadian, and MWP Armies would be interested in an austere vehicle of this type.

18. Existing or developmental items of other services, armies, or countries which might fulfill the requirement.

a. CJ-5
b. International Harvester Scout
c. CJ-3B
d. M422-USMC

19. Communications Security (COMSEC) - No requirement

20. Additional comments.

a. Feasibility of development. If, during the development phase, it appears to the developing agency that the characteristics listed herein require the incorporation of certain impracticable features and/or unnecessarily expensive and complicated components or devices, costly manufacturing methods and processes, critical materials, or restrictive specifications which serve as a detriment to the military value or cost of the item, such matters shall be brought to the immediate attention of the Chief of Research and Development of the Army, and Headquarters, U. S. Army Combat Developments Command for consideration before incorporating into a final design.

b. Based on information received from AMC, a unit cost objective of $1,900.00 is deemed appropriate.

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